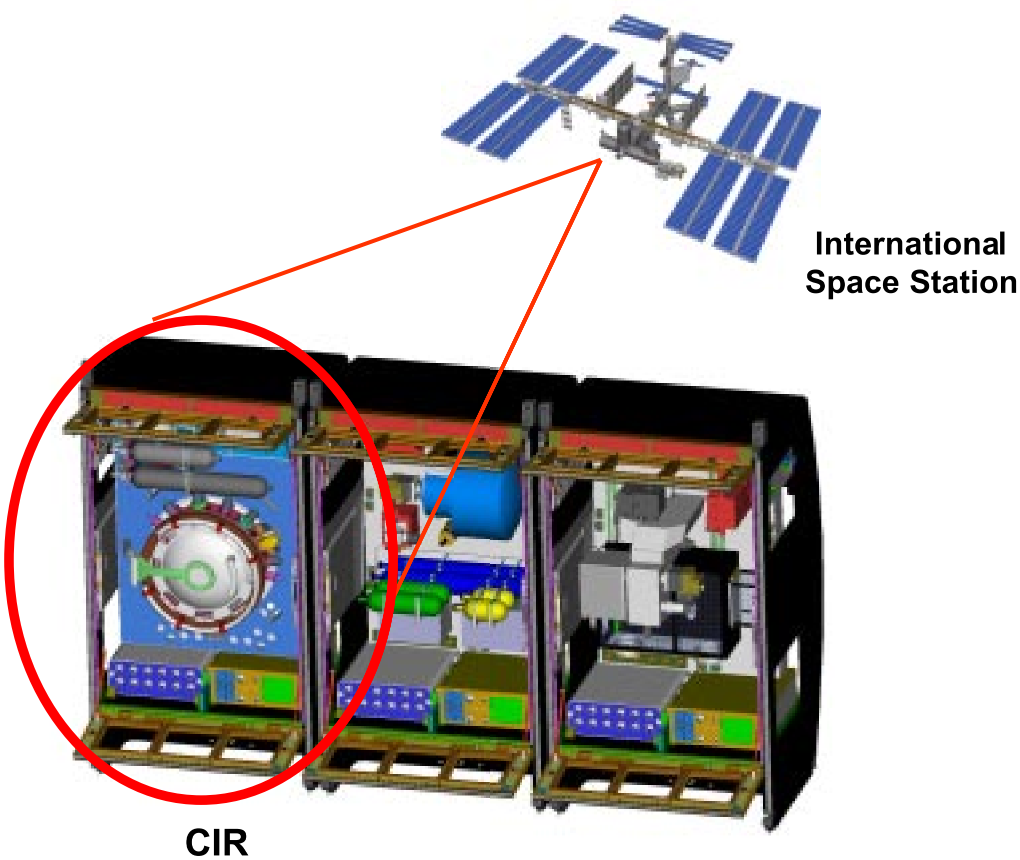
National Aeronautics and Space Administration
John H. Glenn Research Center

Revision: Basic

ISS Fluids and Combustion Facility Combustion Integrated Rack Payload Accommodations



Principal Investigator's Guide

September 2000

Prepared

by

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PREFACE

The International Space Station will provide scientists from industry, academia and the government with unparalleled opportunities for research in space. The ISS will enclose more than 1,716 cubic yards of pressurized space and house six dedicated laboratory modules. The primary facility for microgravity combustion research on-board ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). This facility is being developed to support sustained, systematic research on-board ISS and will be capable of accommodating five to fifteen microgravity combustion experiments per year during the more than ten years that ISS will be operational after assembly complete. The accommodations provided to Principal Investigators by the FCF Combustion Integrated Rack are summarized in this document.

This document is intended to be used by Principal Investigators entering NASA's Microgravity Combustion Science Program and/or those investigators currently in the Program who are seeking combustion experiment flight opportunities using the International Space Station (ISS). In addition to broadly describing the Microgravity Combustion Science Program and future flight opportunities on-board ISS in the FCF Combustion Integrated Rack, this guide outlines the role of the Principal Investigator during the conceptual stage of the experiment development process, including a description of the Science Concept Review held early in the experiment formulation process and the content of the Science Requirements Document (SRD) in which the overall objectives and specific scientific requirements for an experiment are documented by the Principal Investigator.

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MICROGRAVITY COMBUSTION SCIENCE PROGRAM

Combustion is a key element of many critical technologies used in society today such as electric power production, home heating, surface and air transportation, space propulsion and materials synthesis. Effects of gravitational forces impede combustion studies, since combustion involves production of high temperature gases whose low density results in buoyant motion. Gravity, therefore, vastly complicates the execution and interpretation of combustion experiments. Gravity also causes particles and droplets to settle, inhibiting studies of heterogeneous flames. Combustion scientists use microgravity to simplify the study of many combustion processes leading to an enhanced fundamental understanding of combustion processes.

Relevance of Combustion:

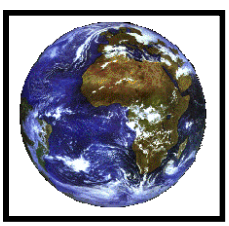
Combustion processes provide 85% of the world's energy needs

Combustion is a primary source of ground transportation, electrical power production, residential and commercial heating, manufacturing and industries

Combustion enables contemporary aircraft and spacecraft propulsion

Unwanted fires and explosions can be harmful to humans and the environment

Pollution control is necessary to maintain a healthy environment Combustion is central to industrial and manufacturing processes



Atmospheric change and global warming need to be controlled. Combustion efficiency is important to conserve our natural resources.

Spacecraft propulsion and fire safety are key concerns for the human exploration and development of space.

Areas of Emphasis in the Study of Combustion:

Combustion Efficiency (Power/Propulsion)
Pollution and Particulate Formation
Fire Prevention, Suppression and Safety
Incineration of Flammable Wastes

Applied Combustion Science & Technology

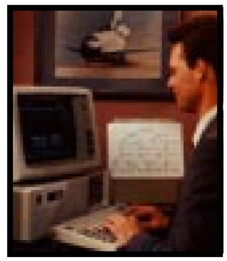
The following areas of research are emphasized in the Microgravity Combustion Science Program:

- Premixed gas flames
- Gaseous diffusion flames
- Combustion of Liquid Fuel Droplets and Sprays
- Combustion of Solid Particles and Dust Clouds
- Flame Spread Across Liquid and Solid Fuel Surfaces
- Smoldering Combustion
- Combustion Synthesis of Materials

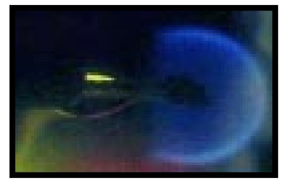
The Microgravity Combustion Science Program seeks a coordinated research effort involving both space-based and ground-based research. Ground-based research forms the foundation of the Program, providing the necessary experimental and theoretical framework for development of rigorous understanding of basic combustion phenomena. This research can eventually mature to the point where it becomes the focus of a well-defined flight experiment.

Microgravity Combustion Science:

M Microgravity permits more fundamental studies of combustion processes and phenomena.
B Buoyancy-induced flows and sedimentation can be virtually eliminated in microgravity.
F Forces and phenomena that are difficult or impossible to study on Earth are revealed more readily, leading to greater basic understanding of combustion.



Microgravity combustion science data is used validate models and develop computational tools to predict combustion behavior.



Research in microgravity permits a new range of combustion experimentation by eliminating nearly all of the gravity-driven forces that lead to buoyancy-induced flows and sedimentation.

Soot Micrograph: Microgravity combustion research has practical significance to a variety of problems in everyday life, such as combustion-generated pollutants.

Technology Benefits: Patented ring stabilized burner could significantly lower NOX pollution and improve energy efficiency of gas appliances.

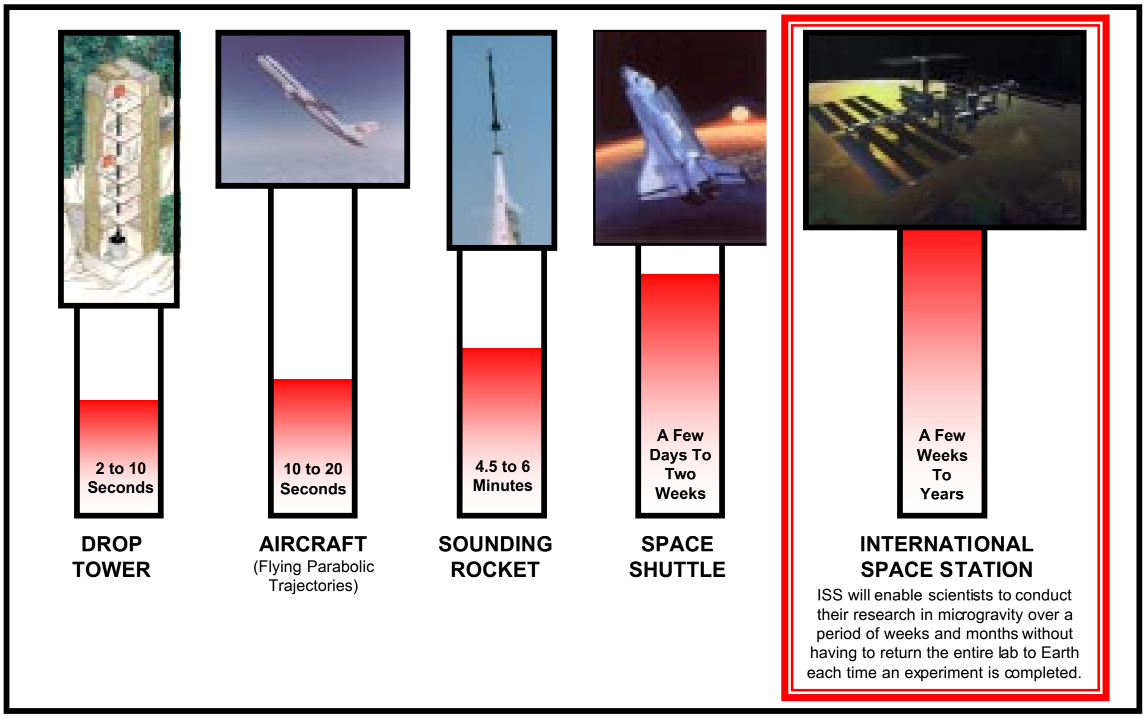
Areas of Study in Microgravity Combustion Science:

Premixed and gaseous diffusion
Combustion of fuel droplets and sprays
Combustion of solid particles & dust clouds
Flame spread on liquid and solid surfaces
Smoldering combustion
Combustion synthesis

The NASA research proposal solicitation process provides researchers from industry, academia and government with the opportunity to apply for funding for combustion flight experiments and for ground-based experimental and theoretical research in microgravity combustion science. NASA Research Announcements (NRA) for microgravity combustion research and flight experiment opportunities are typically issued every other year by the NASA Headquarters Office of Life and Microgravity Sciences and Applications (OLMSA). The next opportunity to submit a proposal for research in the Microgravity Combustion Science Program will be in the fall of 1999. Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including internal NASA and external peer review of the flight experiment in order to be considered for a flight assignment. More information about the selection process and research opportunities can be found on the Internet at the following NASA OLMSA web site: http://www.hq.nasa.gov/office/olmsa/

MICROGRAVITY COMBUSTION RESEARCH PLATFORMS

Microgravity combustion science investigations are accomplished using a variety of research platforms, which support both ground-based investigations and flight experimentation. These research platforms have, in the past, included drop towers, aircraft flying parabolic trajectories, sounding rockets and the Space Shuttle. In the future, the primary platform for microgravity combustion flight experiments will be the International Space Station.



The **2.2 Second Drop Tower** allows investigators to test experimental packages (up to 125 kilograms) in a microgravity environment for a period of 2.2 seconds. Experiments assembled on a drop frame structure are enclosed in a drag shield that has a high weight-to-frontal area ratio and a low drag coefficient. A gravitational acceleration of less than 10^{-4} g is obtained during the fall since the experiment package falls freely within the drag shield. Battery packs provide onboard power to the experiment. Data is acquired by high speed motion picture cameras (frame rates up to 1,000 frames per second), video cameras, and on-board data acquisition systems used to record data supplied by thermocouples, pressure transducers and flow meters. Normal operations provide the opportunity for 8 to 12 drops per day to be performed. More information on the 2.2 second drop tower can be found on the Internet at the following site: http://zeta.lerc.nasa.gov/facility/dtower.htm.

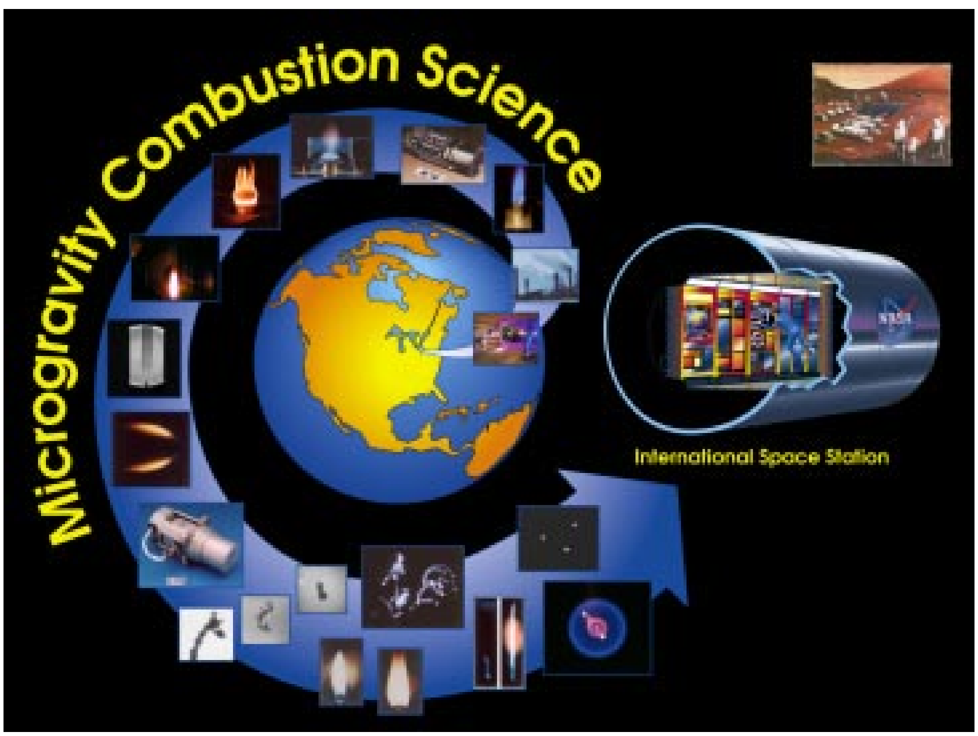
The **5.18 Second Zero-Gravity Facility** has a 132-meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments utilizing hardware up to 450 kilograms are mounted in a one-meter diameter by 3.4 meter high drop bus. Gravitational acceleration less than 10^{-5} g is obtained. Visual data is acquired through the use of high speed motion picture cameras. Also, other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, typically only one test is performed per day. More information on the 5.18 second drop tower can be found on the Internet at the following site: http://zeta.lerc.nasa.gov/facility/zero.htm.

Reduced-Gravity Aircraft are flown in parabolic arcs to achieve 20-25 seconds of microgravity. The aircraft obtains a low-gravity environment by flying a parabolic trajectory. As many as 40 parabolic trajectories may be performed on a typical flight. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth gravity (10^{-2} g). Several experiments, including a combination of attached and free-floated hardware (which can provide effective gravity levels of 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. Both 28 volt DC and 100 volt AC power are available to accommodate a variety of experiments. Instrumentation and data collection capabilities must be contained in the experiment packages. More information on reduced gravity aircraft can be found at the following Internet site: http://zeta.lerc.nasa.gov/kjenks/kc-135.htm.

Sounding Rockets produce higher quality microgravity conditions for longer periods of time than airplanes. Microgravity conditions vary with the rocket type and payload mass. Sounding rockets are basically divided into two parts, solid-fuel rocket motor and payload. The payload is the section that carries the instruments to conduct the experiment and sends the data back to Earth. NASA currently uses 15 different sounding rockets. These rockets can carry payloads of various weights to altitudes from 30 miles (48 km) to more than 800 miles (1,287 km). Scientific data are collected and returned to Earth by telemetry links, which transfer the data from the sounding rocket payload to the researchers on the ground. In most cases, the payload parachutes back to Earth, where it is recovered and reused. Normal operations provide the opportunity for an average of 30 NASA sounding rockets launches each year. Sounding rocket information can be obtained at the following Internet site: http://www.wff.nasa.gov/pages/soundingrockets.html

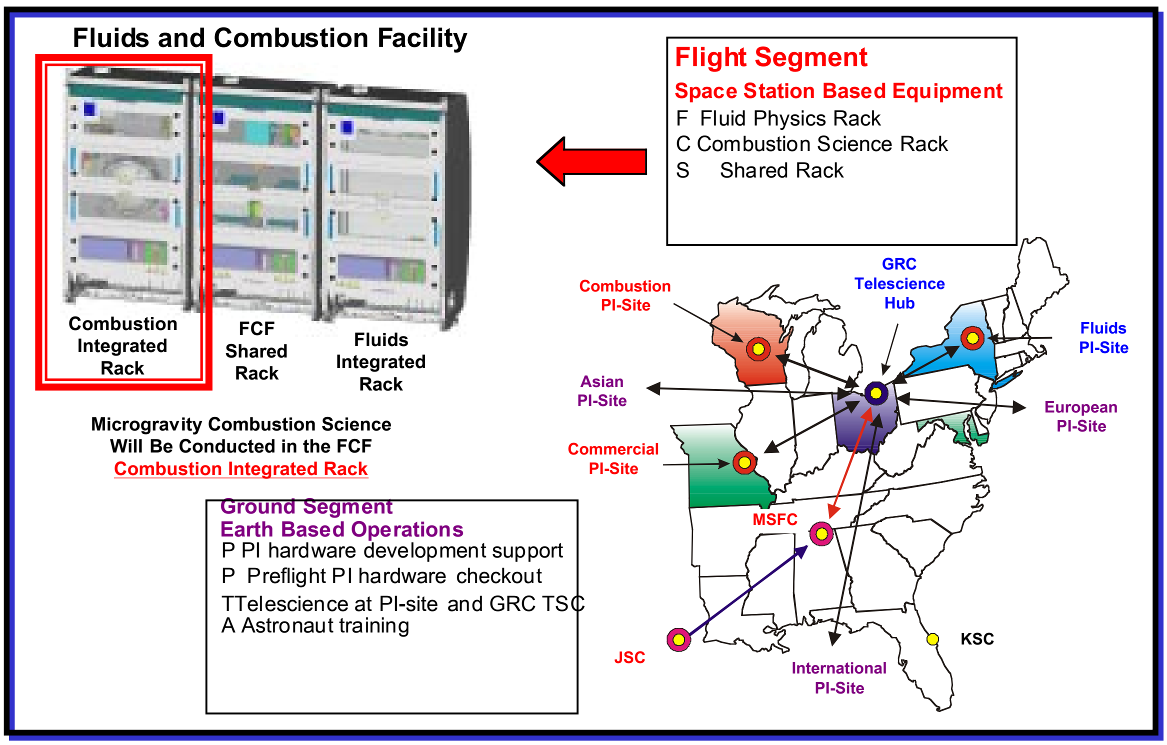
Space Shuttle is a reusable launch vehicle that can maintain a consistent orbit and provide up to 17 days of high quality microgravity conditions. The Shuttle, which can accommodate a wide range of experiment apparatus, provides a laboratory environment in which scientists can conduct longer-term microgravity investigations. A number of primary microgravity combustion flight experiments performed in the past decade used the Space Shuttle as a platform (i.e., in middeck lockers (lockers located in the middeck area of the Orbiter cabin), get-away specials (i.e., small self-contained payloads in cylindrical containers located externally), or in spacelab/spacehab laboratories located in the cargo bay of the Space Shuttle. As NASA proceeds from the Shuttle era to the Space Station era, less microgravity combustion experiments will be conducted on-board the Shuttle and microgravity research activities will transition to ISS. Information on the Space Shuttle can be found at: http://www.shuttle.nasa.gov

The **International Space Station** is a semi-permanent facility that will maintain a low Earth orbit for up to several decades. The International Space Station will afford scientists and engineers a unique on-orbit research facility, in which complex, long-duration experiments can be performed. The ISS will enable scientists to conduct their research in microgravity over a period of several months without having to return the entire laboratory to Earth each time an experiment is completed. The primary carrier of microgravity combustion experiments in ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). General information about the International Space Station can be found at the following Internet site: http://station.nasa.gov.



ISS FLUIDS AND COMBUSTION FACILITY

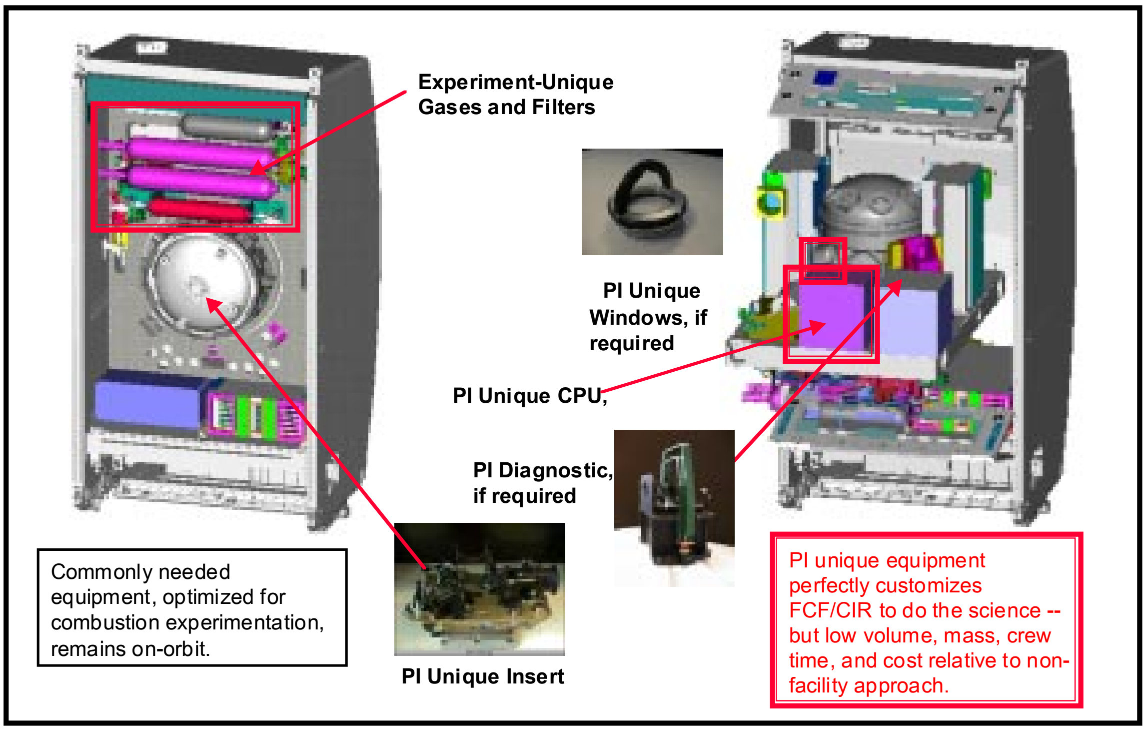
The ISS Fluids and Combustion Facility (FCF) is a modular, multi-user facility that will support Microgravity Fluid Physics and Microgravity Combustion research on board the International Space Station. The FCF will be a permanent on-orbit research facility that will enable NASA's Human Exploration and Development of Space (HEDS) Microgravity Program objectives to be met. The FCF is being designed to support sustained, systematic research in the ISS over the ten to fifteen year lifetime of ISS, after its assembly has been completed on-orbit. The facility is being designed to accommodate 5 to 15 Fluid Physics experiments per year and 5 to 15 Combustion Science experiments per year, depending upon ISS resources and Microgravity Research Program resources that are made available to support investigations in these research disciplines.



The FCF Flight Segment will consist of three on-orbit racks that will be located inside the US Laboratory Module of the ISS. These racks are the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack (SAR). The Combustion Integrated Rack will be optimized to support a diverse range of microgravity combustion science investigations on-board ISS. It will be the first FCF rack deployed to ISS and is currently planned for launch to ISS on UF-3 in 2003. The CIR will initially operate independently from other FCF racks, supporting the first set of microgravity combustion science investigations on board ISS. After other FCF racks are deployed to ISS, the CIR will operate in conjunction with those racks to leverage their capabilities, thereby maximizing combustion experiment through-put and science return from ISS.

FCF COMBUSTION INTEGRATED RACK

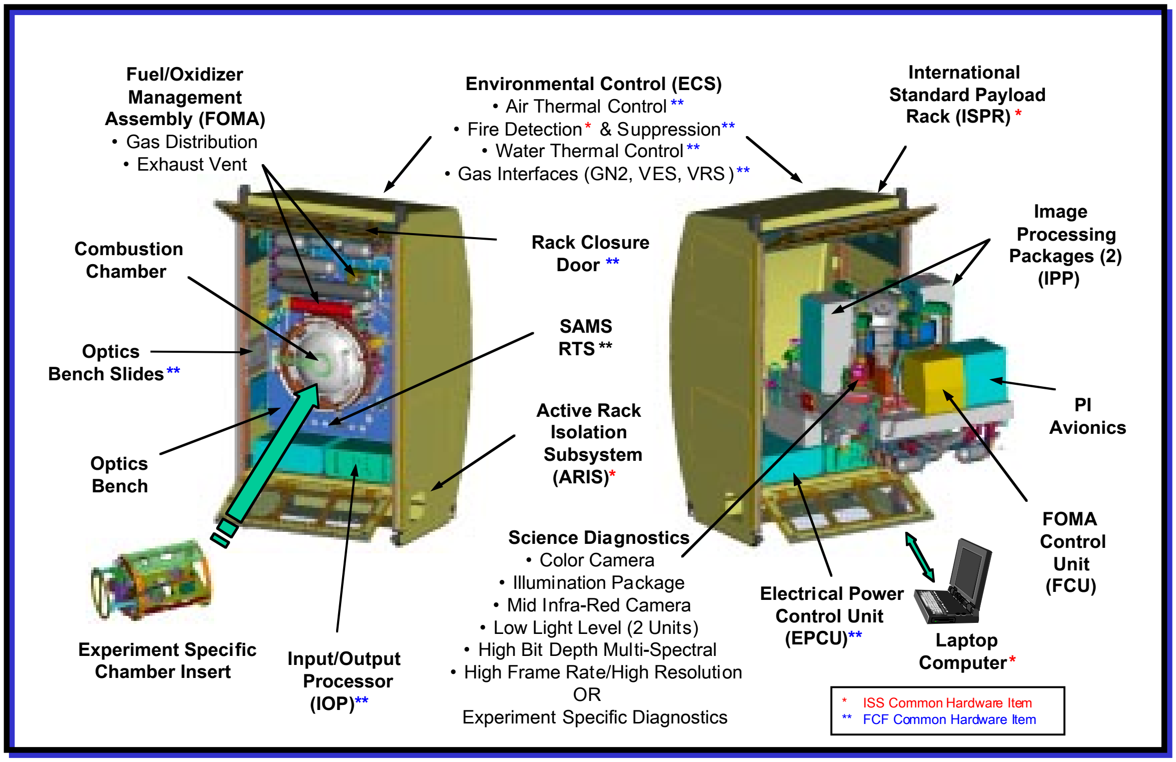
The FCF Combustion Integrated Rack (CIR) will provide a platform for sustained, systematic microgravity combustion research on-board ISS. Principal Investigators will be able to use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravitational effects and thus are difficult to study on Earth. A diverse range of combustion research can be accommodated in the CIR, including (but not limited to) studies of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire suppressants, condensed phase organic fuel consumption, turbulent combustion, soot and polycyclic aromatic hydrocarbons and material synthesis.



The CIR will provide the majority of required hardware and infrastructure to perform combustion science investigations in ISS. In this way the cost and development requirements for individual experimenter's hardware is minimized. However, key components of the CIR will be on-orbit replaceable to enable it to be customized for each new combustion experiment that will be performed in it. The CIR's modular, flexible design will also permit upgrades, incorporation of new technology and provide for on-orbit maintenance during the >10 year life span of the facility.

A Principal Investigator that plans to use the CIR as a research platform for combustion experimentation will typically develop science-specific equipment that will be installed in the CIR to perform the experiment. The following types of hardware and software items may be needed to tailor the CIR to accomplish the specific research objectives of a microgravity combustion experiment: Intrusive diagnostics (i.e. thermocouples); igniters; sample cells; combustion chamber insert; experiment gases (contained in FCF-provided bottles); exhaust vent filter(s); science-specific diagnostics; Specialized electronics; control software (scripts).

CIR Elements / Subsystems

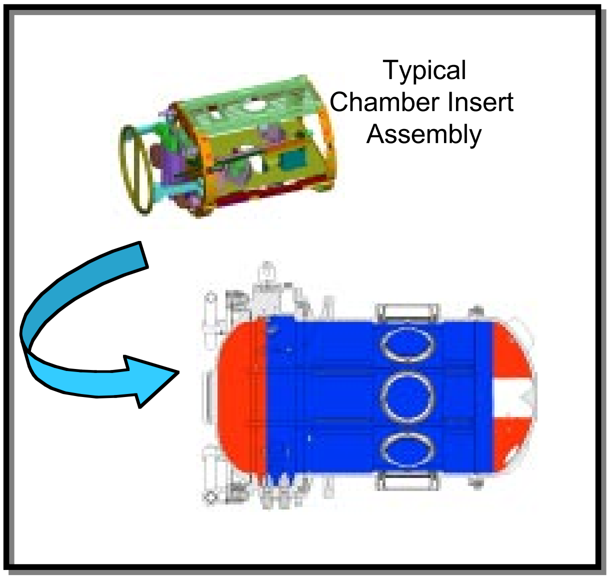


The CIR will provide an optics bench for combustion experimentation in ISS. The layout of the bench can be optimized for each new combustion experiment. A 100-liter combustion chamber is located in the center of the optics bench. It incorporates eight windows, which can be replaced on-orbit. Windows will be selected for the wavelength of lights most important to the PI and/or changed out if contaminated. The CIR's Fuel Oxidizer Management Assembly (FOMA) will deliver gaseous fuels, diluents and oxidizers to the combustion chamber. The FOMA can support static and dynamic mixing of gases with very high precision and accuracy. This assembly also provides for access to vacuum and cleaning of combustion by products to make them safe to vent overboard after the experiment is conducted. The composition of gases in the combustion chamber will be measured using the CIR gas chromatograph. Illumination sources and cameras covering a wide spectral range for various scientific measurements can be mounted outside each combustion chamber window. These cameras and light sources can be removed and replaced quickly, with all electrical and data connections made automatically upon crew installation. The final alignment of the cameras and their operation will be by remote control from Earth.

CIR RESOURCES AND USER INTERFACES

Combustion Chamber

The Combustion Chamber is pressure vessel designed to withstand 135 psia of Maximum Design Pressure (MDP). The maximum capacity is 100 liters. The Combustion Chamber accepts a Chamber Insert Assembly **(CIA)** with maximum dimensions of 600 mm in length, and 396 mm in diameter.



The blue area in the figure indicates the region into which a CIA can be placed.

Areas in red indicates areas that may be used but require consultation with FCF.

White areas indicate locations of known permanent protrusions into the chamber volume.

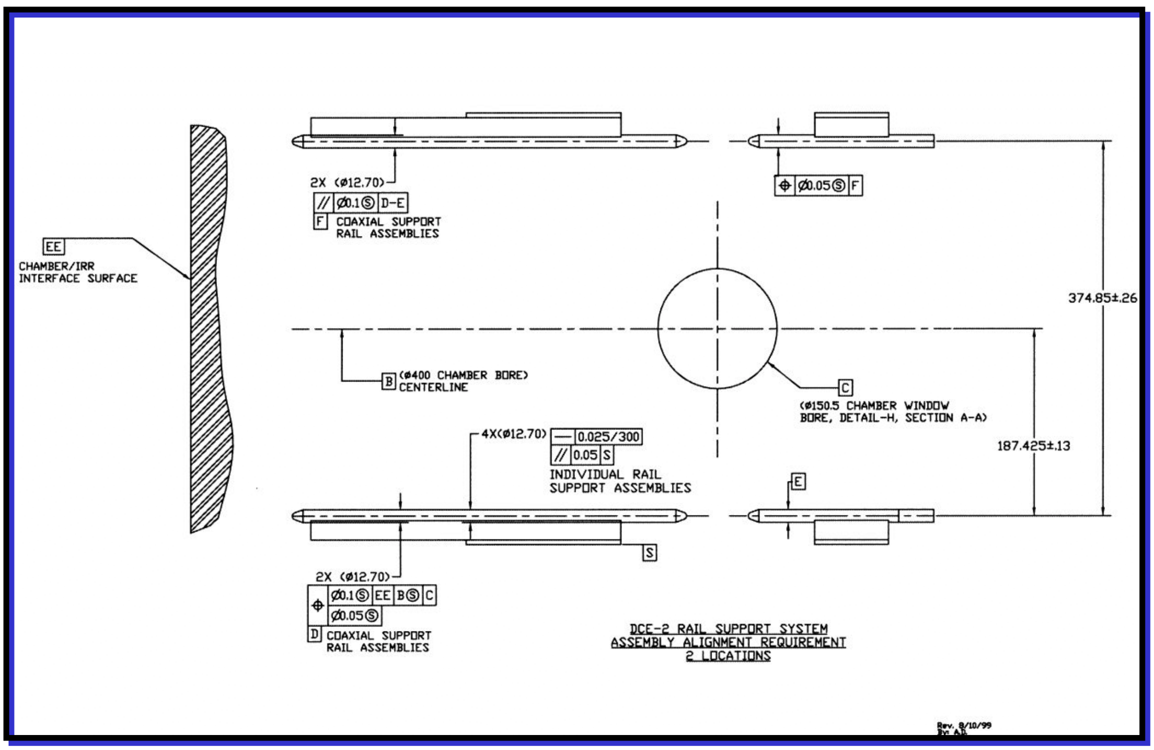
The Chamber contains eight 115 mm diameter field of view replaceable windows allowing for three simultaneous orthogonal views. The window materials that are CIR provided are 8 Sapphire windows 8mm thick with a transmission wavelength of 200nm to 5µm. Since the windows are removable, it is possible for the experimenter to provide the windows that best comply with the experiment imaging needs.

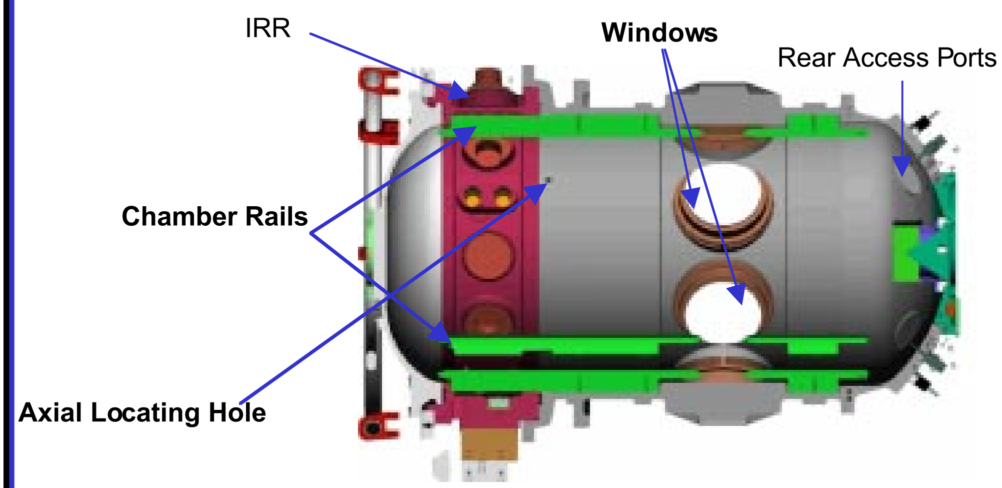
CIA/Chamber Interface - Mechanical

The CIA mounts to the chamber using two rails located inside the chamber. To sets of rails are provided positioned 22.5° above and below the horizontal axis of the chamber. This allows the CIA be positioned in two different orientations and make use of all eight windows if necessary without the need of reconfiguration of diagnostics.

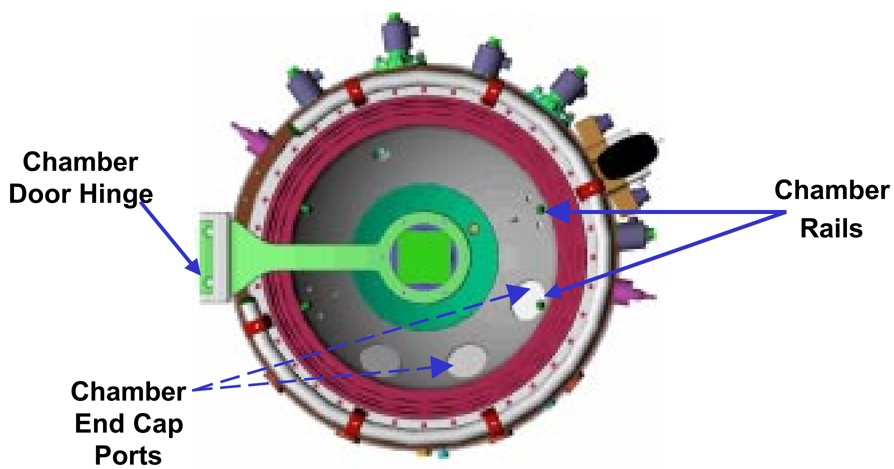
The chamber rails provide accurate positioning of the CIA with high repeatability. Rail parallelism is kept within 250 μm from to back of the chamber. Accuracy for CIA centering respect to the center of the chamber is 100 μm.

Chamber Rails Details





Combustion Chamber Longitudinal Section



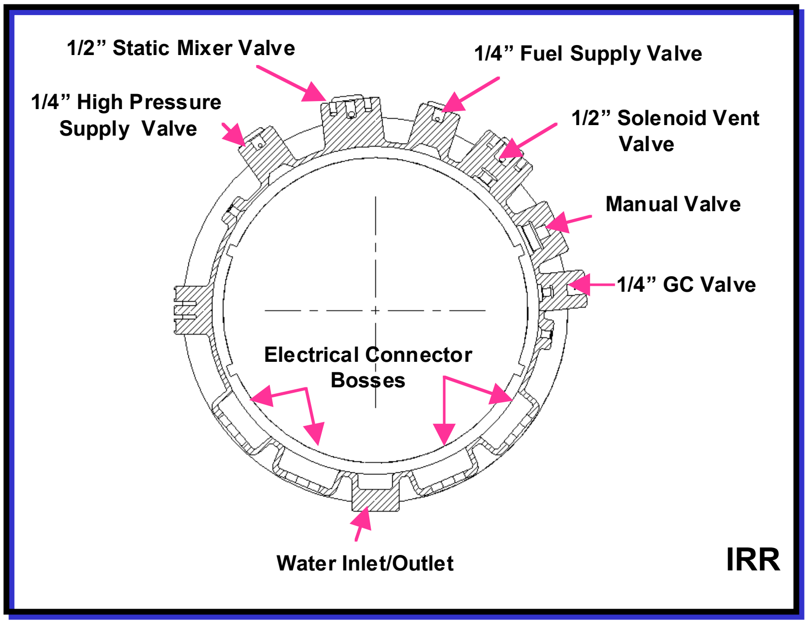
Combustion Chamber Cross Section

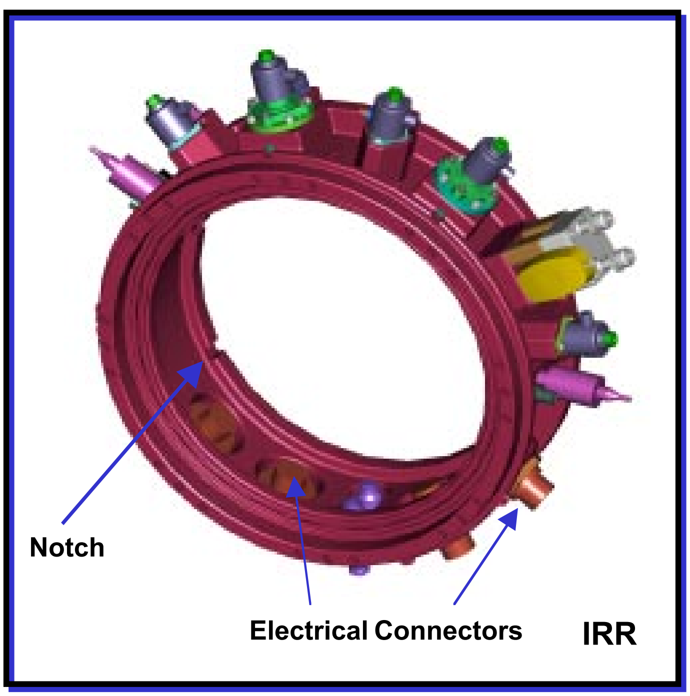
The chamber also provides two ports of 63.5 mm diameter in the rear end cap for additional chamber access. These ports can be utilized for additional windows if the experiment requires them. A 43.5 mm diameter area is left after the space required for the O-rings is subtracted. Attachment of this windows will be by 4 bolts.

CIA/Chamber Interface - Electrical & Fluids

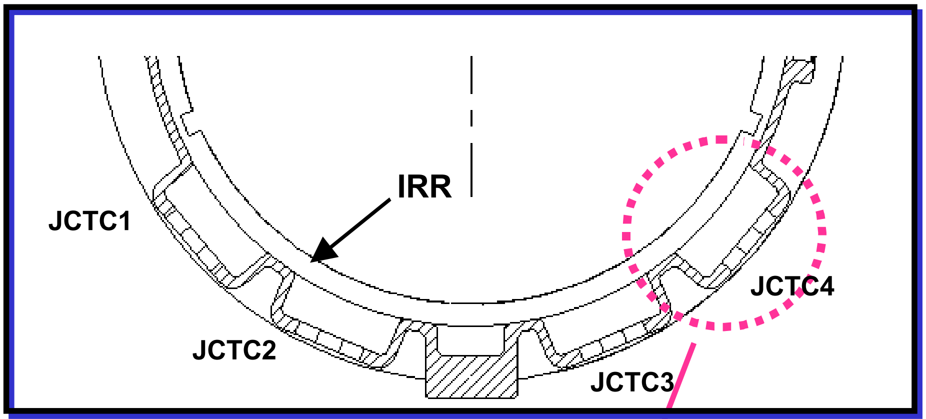
The electrical and fluids interfaces between the combustion chamber and the CIA is achieved through the Interface Resource Ring (**IRR**).

Fluid connections allow injection of fuel, oxidizer and diluent into the chamber. In addition a line for Station supplied water is provided for CIA cooling if needed.





Notches are cut in the minor diameters to allow the CIA to interface with the chamber. This interface is design to prevent the CIA to extend over the IRR and protect the electrical connections and instrumentation.



Electrical Connections Specifications

•**Feed-throughs**

4 Insert Type MIL-C-38999 connectors with

JCTC1 : 100 - #22 Contacts

JCTC2: 55 - #20 Contacts

JCTC3: 21 - #16 Contacts

JCTC4: 100 - # 22 Contacts

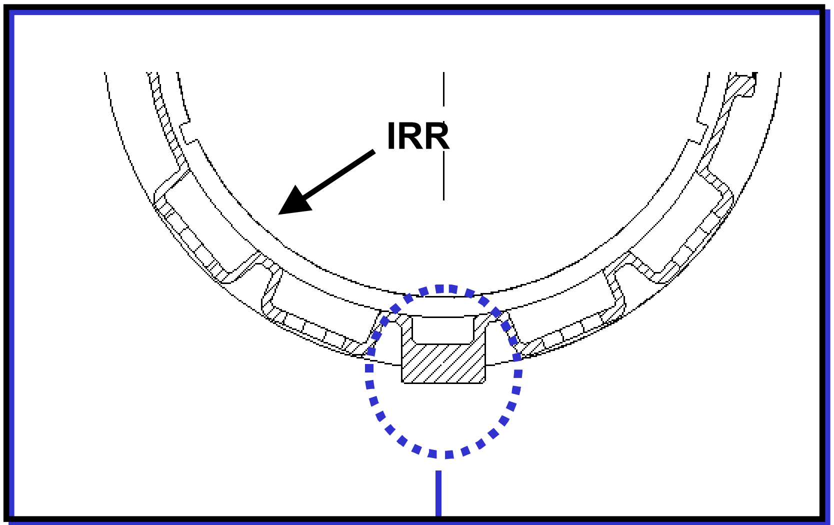
Fiber Optic, Multi-mode 200 Core/225 Cladding

Fiber Optic, Single-Mode 9.0 Core/125 Cladding

•**Fiber Optic Cable Specifications** (Non-polarizing)

Core Diameter (μm)	200+/-5.0 (MM); 9.0+/-1 (SM)
Cladding Diam.(μm)	225+/-10 (MM); 125+/- 1 (SM)
Numerical Aperture	>0.20 (MM); >0.13 (SM)
Jacket (μm)	245+/-15 (MM); 250+/-15 (SM)
Operating Wavelength (nm)	500-1100 (MM); 1550 (SM)
Cutoff Wavelength (nm)	NA (MM); <1430 (SM)

(MM) Multi-Mode *(SM) Single-Mode*



Fluid Connections Specifications

-06 Male QDs with

-06 Straight Thread & O-Ring (MS33649)

51194-3-06-1-V-TF-06-**P**

51194-3-06-1-V-TF-06-**B**

51194-3-06-1-V-TF-06-**Y**

51194-3-06-1-V-TF-06-**G**

Fuel Oxidizer Management Assembly (FOMA)

The FOMA provides the ability to safely deliver all gaseous fuels, diluents and oxidizers required to perform combustion experiments in the chamber. The FOMA can also sample the test chamber environment via a Gas Chromatograph (GC) and control venting of chamber gases, at acceptable concentration levels, to the ISS Vacuum Exhaust System (ISS VES).

The FOMA consists of two packages, the Gas Delivery Package (GDP) and the Exhaust Vent Package (EVP) which includes the GC.

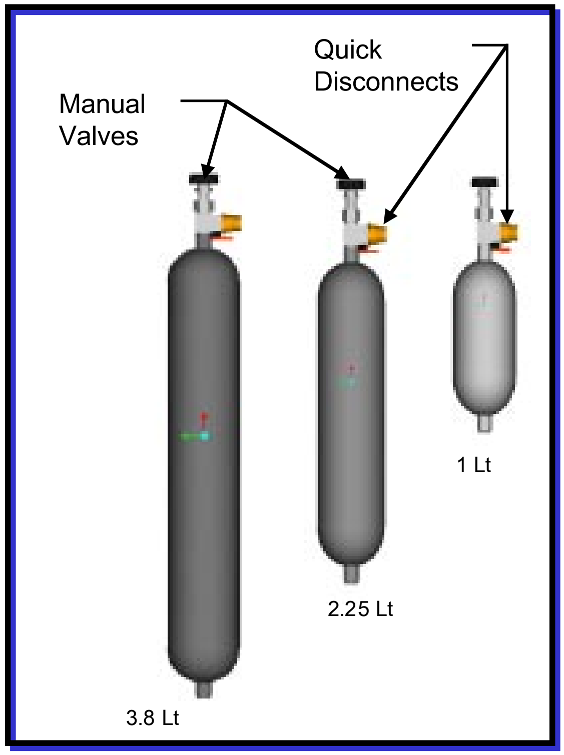
The desired gases are supplied by the experimenter in CIR provided bottles. The gases can be either pre-mixed or pure. The FOMA provides the interface for the bottles as well as ISS supplied Nitrogen. The crew will be able to change out bottles when required. The FOMA also provides gas regulation control to the chamber.

Gas Supply and Distribution Package

On-orbit gas blending up to 3 gases

Flow-through with real time venting

Accommodates pre-mixed gases



Gas Supply Bottles

Oxidizers

- 1.0 L up to 85% O2
- 2.25 L up to 50% O2
- 3.8 L up to 30% O2

Fuels: 1.0 L and 2.25 L

Diluents: 1.0L, 2.25L, 3.8 L

Stainless steal, commercially available

Quick disconnect attachment to manifold

Pressure: ~14 MPa (~2000 psig)

On-Orbit Gas Blending Capability

On-Orbit gas blending can be accomplished by two methods, partial pressure and dynamic mixing. Both of these methods can be used to pressurize the Chamber to the desired pressure and gas ratio. The dynamic mixing method can accommodate experiments requiring flow through.

Oxidizer/Diluent Flow Rates

30 SLM Max flow rate from each manifold

Total 90 SLM Maximum flow rate

Fuel Flow Rate

2 SLM Maximum flow rate

Gas blending accuracy:

Partial Pressure Method: Less than +/-0.35% absolute

Dynamic Method:

Oxygen blends <25% : +/- 0.3% absolute

Oxygen blends >25% : +/- 2% of reading

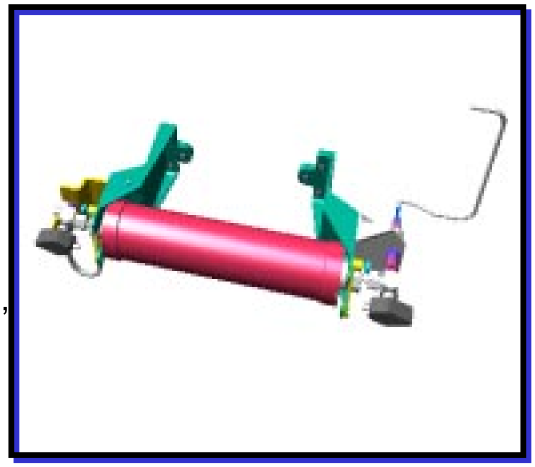
Exhaust Vent Package (includes GC)

An adsorber cartridge/re-circulation loop is used to clean post-combustion gases. The GC is used to sample the Chamber environment to ensure compatibility of combustion by-products with ISS limits.

3 sizes of adsorber cartridges are provided
- 76.2 mm ID x 355 mm long
- 50.8 mm ID x 279 mm long

Adsorber Cartridges have QD connections for crew replacement.

Adsorber Cartridge contents:
- •Silica gel: removes water, alcohols, aromatics,
- •olefins
- •Molecular sieve: removes water
- •Activated carbon: removes hydrocarbons
- •Lithium hydroxide: removes CO_2 and acid gases



Adsorber Cartridge

The Gas Chromatograph (GC) is capable of measuring the chamber contents for hydrogen, methane, propane, oxygen, nitrogen, carbon monoxide, carbon dioxide, sulfur hexafluoride and detecting water.

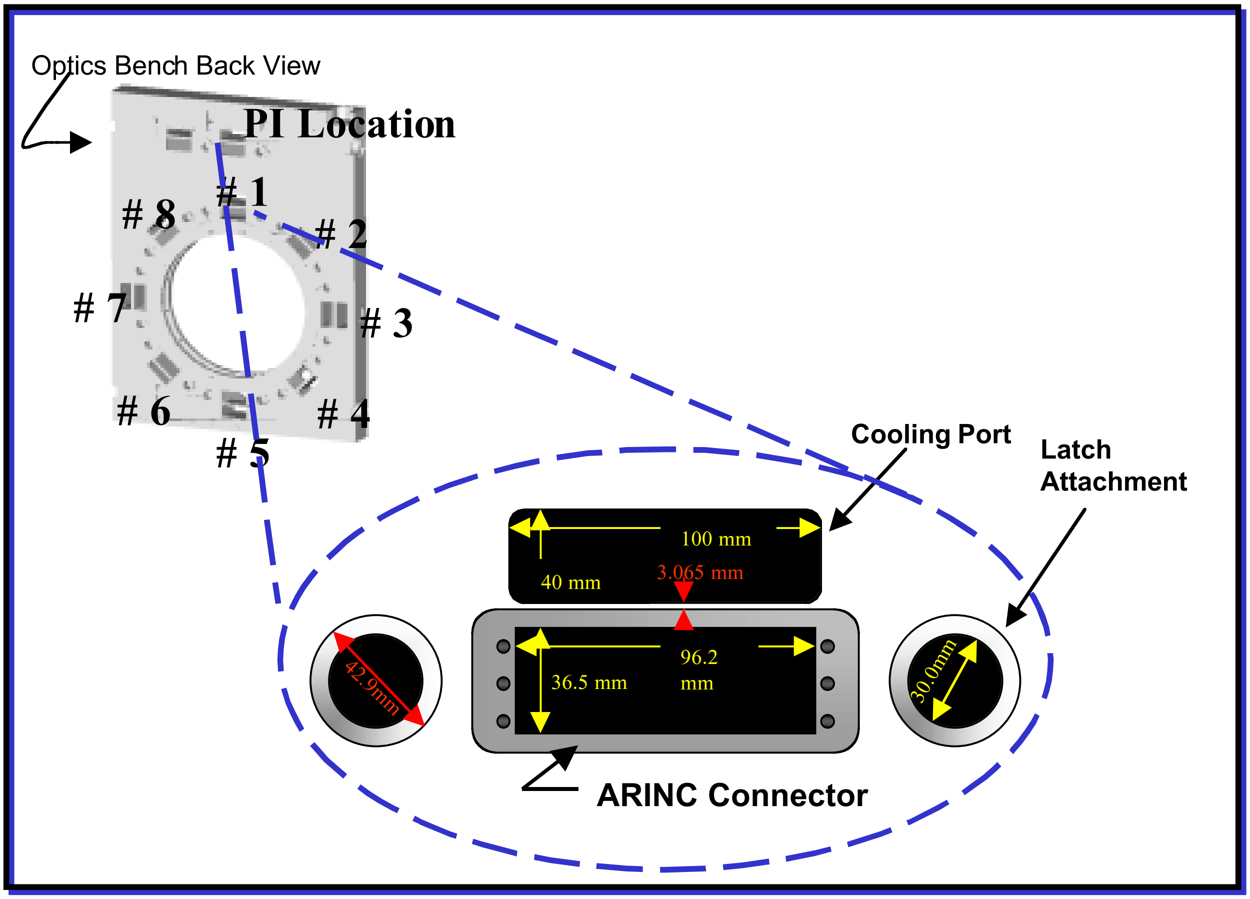
Optics Bench Interfaces

The Optics Bench provides structural support, electrical connections and mounting locations for all science support hardware. The bench is mounted on slide assemblies for fold down to facilitate access.

The bench contains 8 Universal Mounting Locations (UML) for diagnostic package mechanical and electrical interface providing common power, command/control and data connection, air cooling, structural mounting and optical alignment. Packages can be positioned on the bench with an alignment accuracy of 100 μm.

One additional UML is provided for exclusive use of the experimenter's avionics box. This location is labeled PI Location.

UML Specifications



Even UMLs and UML #1 contain

- 4 fiber optics
- 1 four to eight Amp power circuit
- 1 Analog video (STP-Shielded Twisted Pair)
- 25 Spare #22 gage lines
- 1 Camera sync signal
- 1 CANbus Channel
- 1 UML ID Code - 6 bits

Odd UMLs (except UML #1) contain

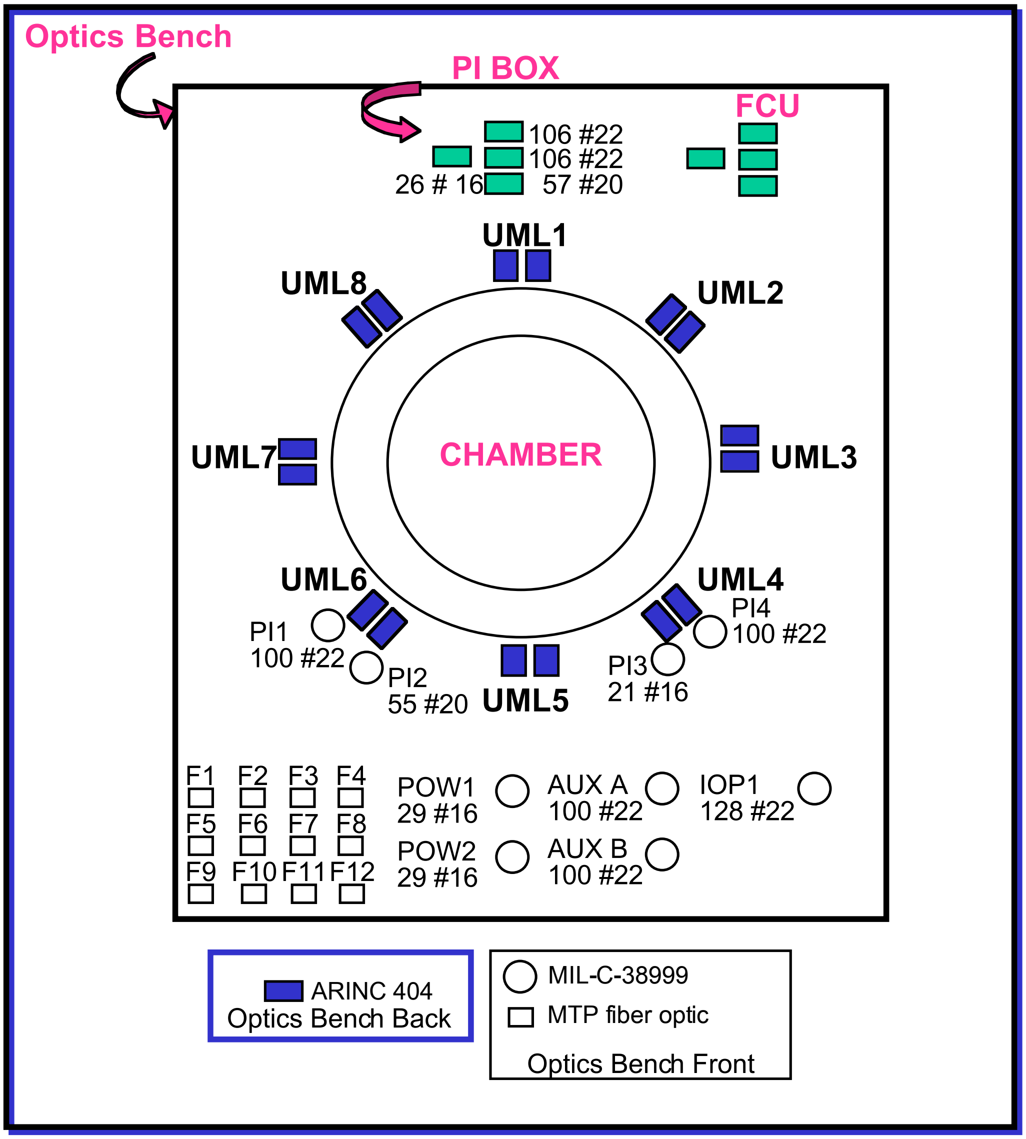
- 8 fiber optics
- 2 four to eight Amp power circuit
- 2 Ethernet
- 2 Analog video (STP)
- 25 Spare #22 gage lines
- 1 Camera sync signal
- 1 CANbus Channel
- 2 UML ID Code - 6 bits

Connector Specification (UML #1 through #8)

•ARINC 404

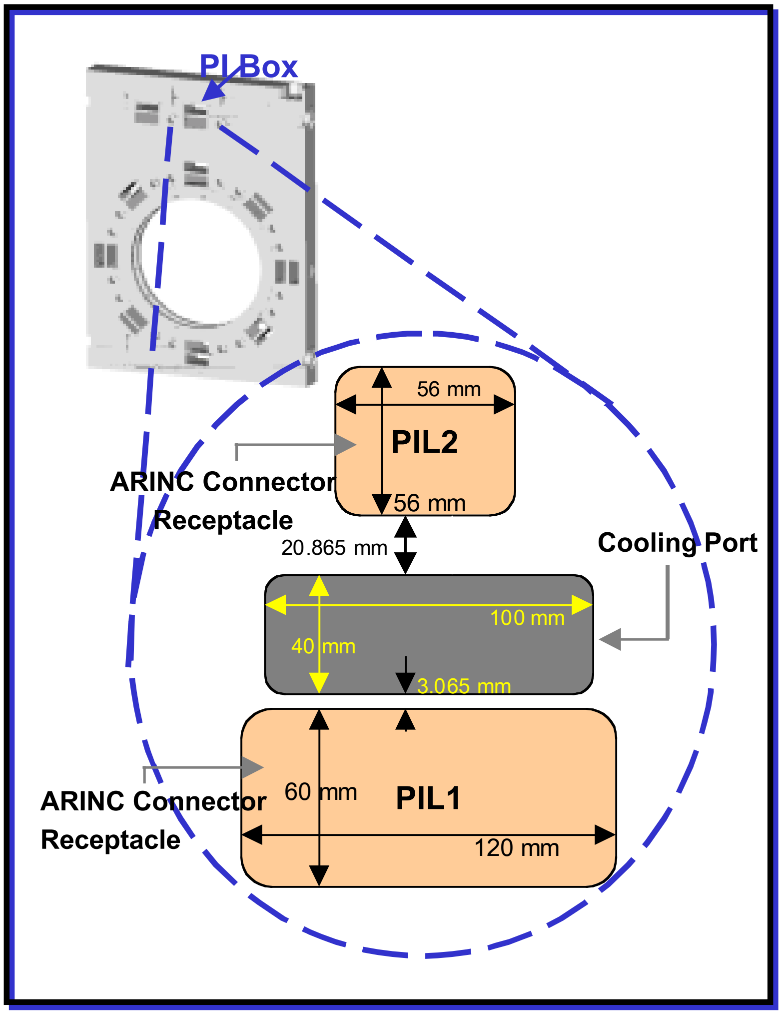
Receptacle: DSXN2R-S106P-S26S-6301 (Mfgr.: Radiall)

Plug: DSXN2P-S106S-S26P-6001 (Mfgr.: Radiall)



The Optics Bench contains a front patch panel to allow for connections between UMLs when the bench is configured for experiment specific diagnostic package requirements. By patch panel configuration, connections between diagnostics and image processing packages and rack to rack communications are possible.

PI Location Connectors (PIL1 & PIL 2)



Fiber optics are used for all diagnostic package data and control signals between the PI location and any UML.

Power into chamber can be routed through the PI avionics box or directly from the EPCU.

The reconfigurable front patch panel jumpers allow communication from PI box location to the chamber, any UML, or the IOP with 22, 20, and 16 gage wire or with single mode or multimode fiber optics. Paralleling 4A, 28Vdc power circuits in harness between the EPCU and the optics bench allows power level adjustment to any location.

<u>Connector Specification</u>

ARINC 404 (PIL1)

Receptacle: DSXN3R-S106P-S106P-S57S-6301

Plug: DSXN3P-S106S-S106S-S57P-6001

•ARINC 404 (PIL2)

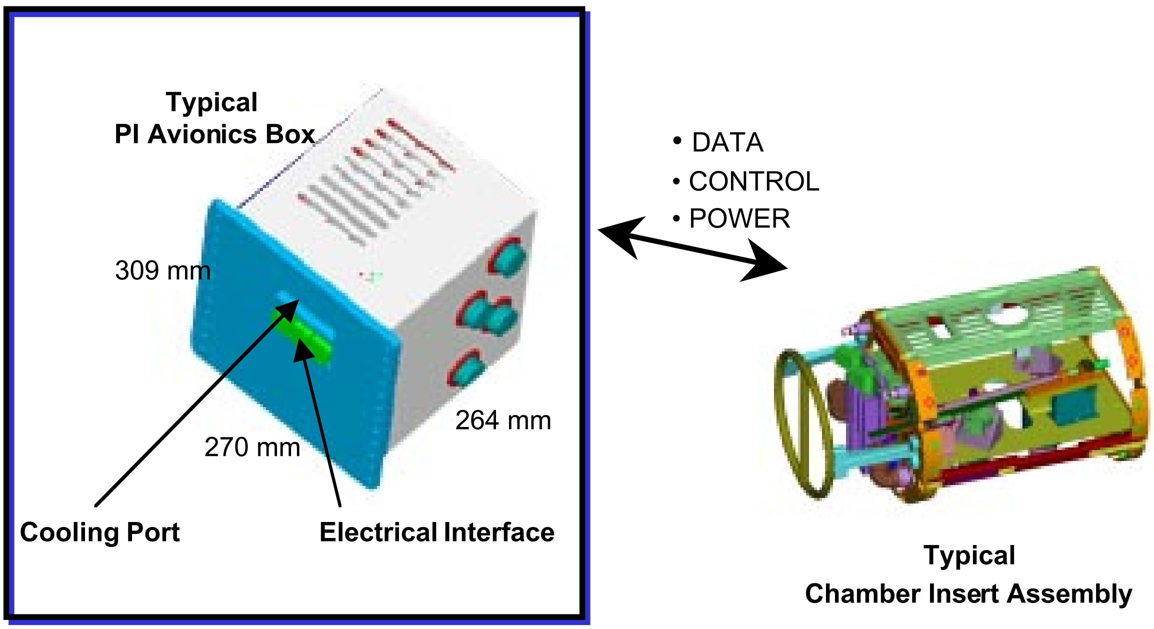
Receptacle: DSXN1R-S26S-6301

Plug: DSXN1P-S26P-6001

S before number indicates crimp contacts **S** or **P** after number indicates **S**ocket or **P**in

PI Avionics Box

It is FCF design philosophy to allow independent development of PI specific apparatus in a low cost environment. The PI avionics box is supplied by the experimenter and it is intended to provide tight, closed-loop control of PI specific equipment such as the CIA in addition to providing data acquisition and signal conditioning for PI provided diagnostics.



PI Location Available Resources

- •3 lines 120 VDC @ 4 amps DC
- •1 Ethernet Channel
- •1 CANbus Channel
- •3 Analog Video, Shielded Twisted Pair to IOP
- •2 Coaxial to Chamber
- •Fiber Optics Access to UMLs via patch panel
- •Camera sync signal
- •Connections from PI Box to Chamber
    - •180 #22 AWG
    - •54 #20 AWG
    - •16 #16 AWG used for Power, Coax and Fiber Optics

Power/Current Resources

The CIR offers the following power and current capabilities to payloads.

28 VDC
2 lines @ 8 ADC (448 Watts) are available at UMLs 1, 3, 5, 7, PI Avionics Box and Chamber

120 VDC Power Outputs
6 circuits @ 4 Amps each
2 EPCU Rear Output Connectors, each having 3 power circuits and remote circuit configuration control pins. Type and location for interface to PI is TBD.

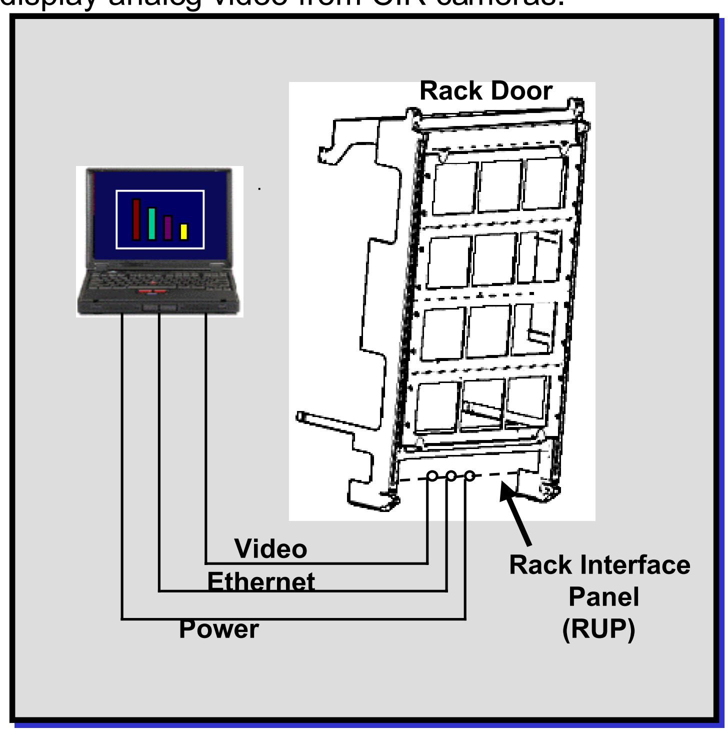
Thermal Resources

All packages mounted on the Optics Bench are Air Cooled by the CIR Air Thermal Control Unit (ATCU). Air is supplied to the packages through the bench air port at 77°F (25°C).

Water cooling is provided to the chamber by the Water Thermal Control Unit at a temperature of 65°F (18.3°C).

Station Support Computer (SSC)

The SSC provides the crew interface for experiment commanding, control and health and status monitoring of the CIR during operations. Also may be used to display analog video from CIR cameras.



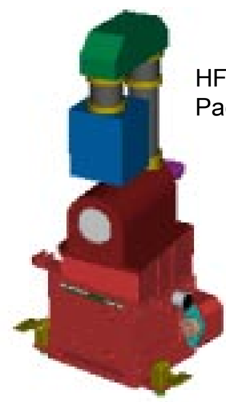
The SSC is an IBM Thinkpad 760 XD (Model 9546U9E) with 3 GB HDD and 64 MB RAM. The operating system is Windows NT 4.0 with Internet Browser (Internet Explorer).

CIR Diagnostics

CIR Diagnostics are designed in the modular form. This allows for the independent design and configuration of optical subassemblies that can be combined to form multiple packages and fulfill the requirements of many experimenters minimizing the amount of on-orbit hardware.

Seven Packages will be launched pre-assembled for PI use:

- •High Frame Rate /High Resolution (HFR/HR) Package
- •High Bit Depth Multi-Spectral (HiBMs) Package
- •Color Package
- •Low Light Level UV (LLL-UV) Package
- •Low Light Level IR (LLL-IR) Package
- •Mid-IR Package
- •Illumination Package

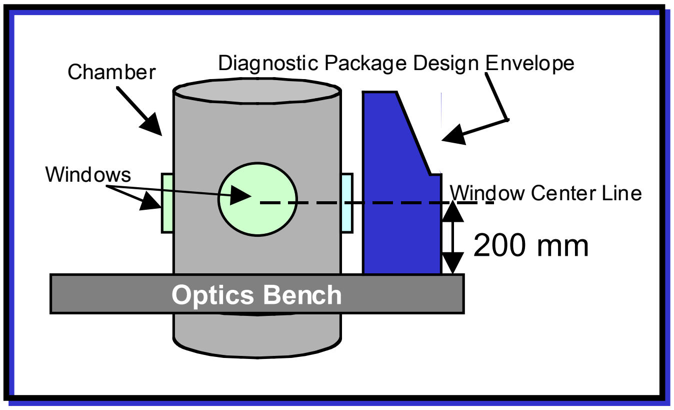


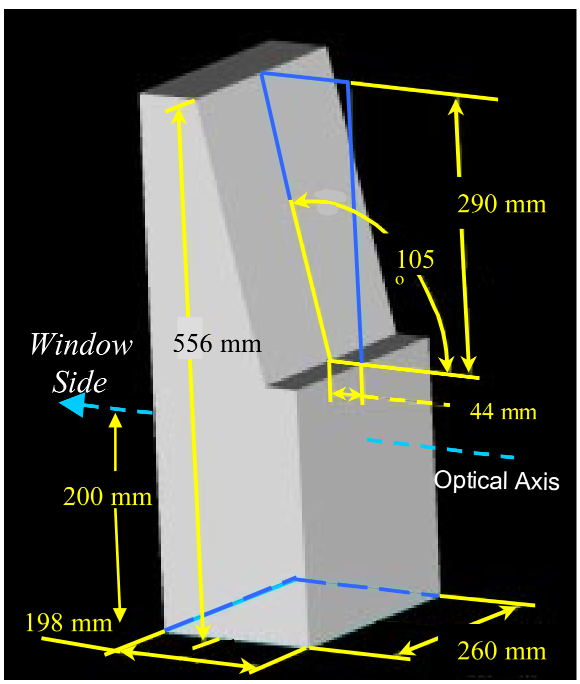
The the following chart lists the features and capabilities of the pre-assembled CIR packages and their applications.

Package	Application	Pixels	FOV (mm)	Resol. (lp/mm)	Bit Depth (bits)	Run Time (min)	Frame Rate (fps)	Spectrum (nm)	Sensitivity	Features
HiBMs	- Soot Volume Fraction - Soot Temp. - Shadowgraph	1024 or Bin 2x2	80 & 50 dia. Telecentric	5 & 10	12	20 @ 15fps	15	650 – 1050	N/A 1200K-2000K 0.8K/mm	Manual iris
HFR/HR	High Frame Rate High Resolution	512 1024	10 sq. (37 total) Telecentric	12 @ 50% mod. 20 @ 50% mod.	8	20 @ 110fps or 30 fps	110 30	450 – 750	600 lux	Centroid Tracking Auto-focus Event Trigger
Color	Configuration Verification	512	58-350 sq. zoom	4.4 - 0.7	24	27 @ 30 fps	30	400 – 1050	2 lux	Manual iris Manual focus
Low Light Level	OH Emissions CH Emissions	1024	48-212 sq. zoom	12.1 - 2.4	8	20 @ 30 fps	30	280 – 700	6x10E-9 ft-candle	Manual iris Manual focus
Low Light Level	H_2O Emissions	1024	48-212 sq. zoom	12.1 - 2.4	8	20 @ 30 fps	30	500 – 875	4.4xE-9 ft-candle	Manual iris Manual focus
Mid-IR	Absorption Lines Temperature	320 x 244	183 x 138	0.9	12	20 @ 60 fps	60	1000 – 5000	-10C to 1500C	Manual focus
Illumination	Calibration Bkgrnd Illum. Interferometry	N/A	80 dia. Collimated	N/A	N/A	N/A	N/A	3000K 675	5mW output	Light Source Selectable

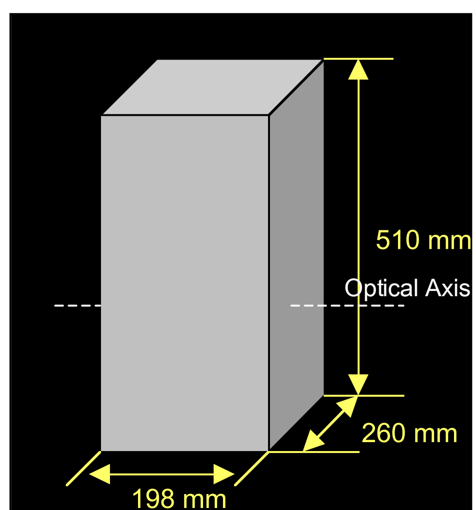
Because of their modular nature, packages can be easily reconfigured by re-assembly of modules to allow for additional features.

CIR provided packages can also be replaced by PI provided hardware if required.



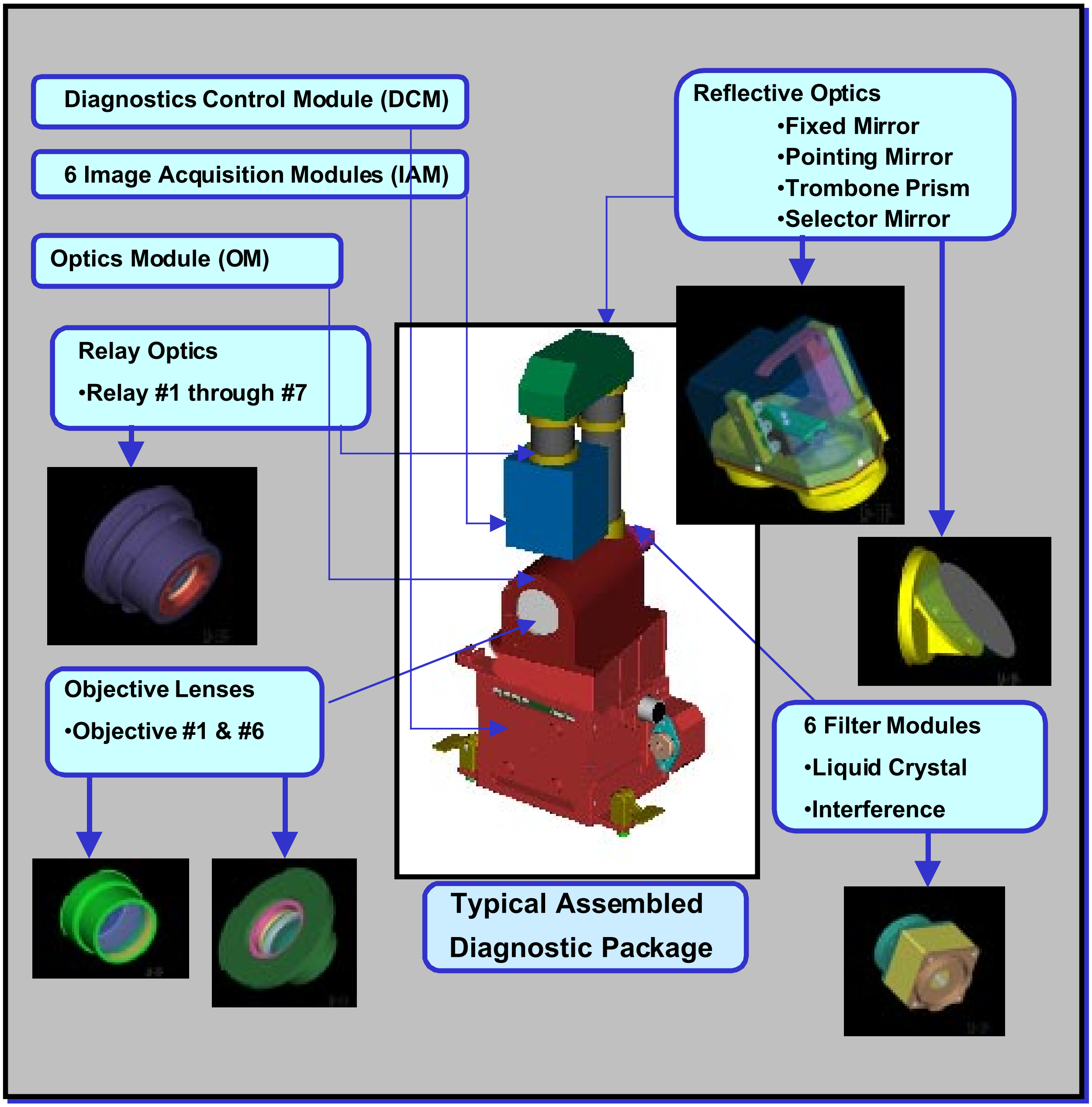


Package maximum design envelope for UML #1 through 8



Package maximum design envelope for UML # 3, 4, 5, 6 & 7

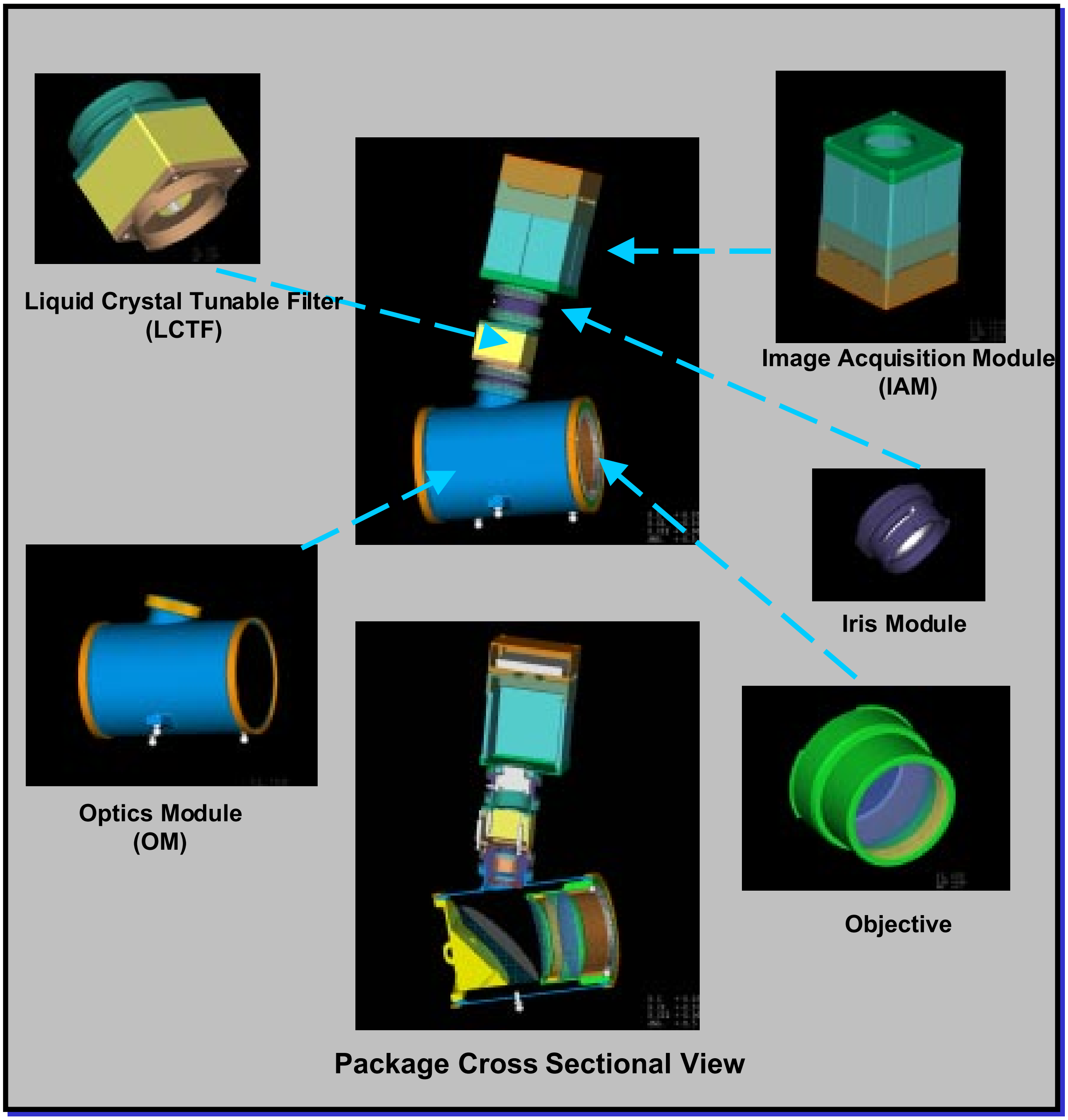
CIR Diagnostics Module Kit



A CIR typical diagnostic package includes but it is not limited to, a Diagnostics Control Module, the Optics Module containing an objective, a reflective module to provide optical path fold, a relay or imaging optics, optical filter (if required) and the Image Acquisition Module that includes camera and power supply.

CIR provides a variety of lenses, mirrors and filters to select the appropriate set of optics for imaging needs.

Typical Package Assembly

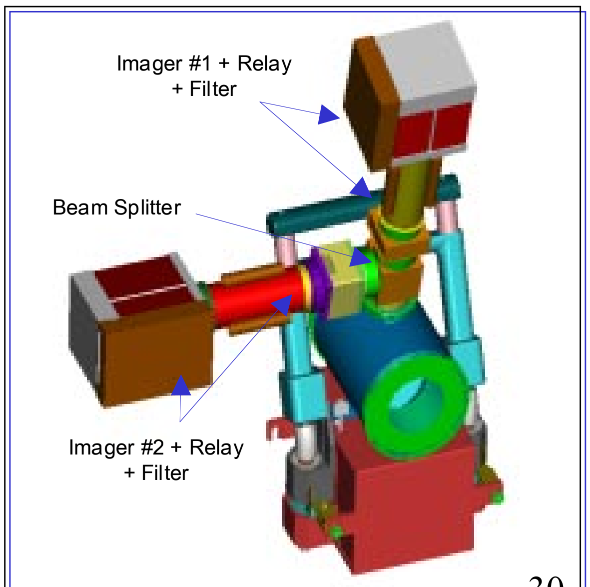


One additional module is included in the set. An optical path compensator is included to be used when the LCTF is not needed. A similar design philosophy can be followed by the experimenter to accommodate the appropriate optical components maintaining the total optical track.

The CIR provided kit of lenses and their optical specifications are shown below. They may be used to configure CIR or PI provided diagnostic packages.

Optical System	System EFL	Obj. NA	Track Length	Sys. FOV	Wave-length	Description
HFR/HR Objective Lens + HFR/HR Relay Lens #1	57850 mm (Inf.)	0.0023	Obj: 32.0mm	10mm sq.	450-750 nm	Telecentric Design
			Rel: 13.5 mm			
HiBMs Objective Lens + HiBMs Relay Lens # 1	259 mm	0.009	Obj: 50.3mm	80 mm Dia	650 - 1050 nm	Telecentric Design
			Rel: 47.3 mm			
HiBMs Objective Lens + HiBMs Relay Lens # 2	TBD	TBD	*Under Design*	50 mm Dia	650 - 1050 nm	Telecentric Design
Color Objective Lens # 1 + Color Relay Lens	43.6 mm - 26.1 mm	0.025 - 0.014	Obj: 81.9 mm	50 - 100 mm	400 - 700 nm	2X Zoom Relay Design
			Rel: 129-167 mm			
Color Objective Lens #2 + Color Relay Lens	27.1 mm - 14.0 mm	0.015 - 0.008	Obj: 81.9 mm	100- 200 mm	400 - 700 nm	***Note** : Design*
			Rel: 129-167 mm			*still being optimized*
Color Objective Lens #3 + Color Relay Lens	15.9 mm - 7.9 mm	0.010 - 0.005	Obj: 81.9 mm	100- 200 mm	400 - 700 nm	***Note** : Design*
			Rel: 129-167 mm			*still being optimized*
Low Light Level UV Objective Lens			*Under Design*		250- 700 nm	
Low Light Level UV Relay Lens			*Under Design*		250 - 700 nm	
Low Light Level NIR Objective Lens			*Under Design*		400 - 900 nm	
Low Light Level NIR Relay Lens			*Under Design*		400 - 900 nm	
Mid IR Objective Lens			*Under Design*		1000 - 5000 nm	
Mid IR Relay Lens			*Under Design*		1000 - 5000 nm	

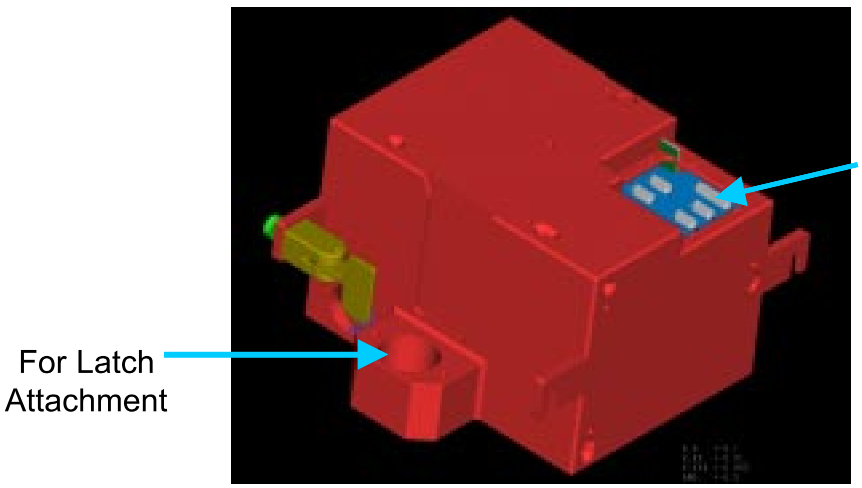
Reconfiguration of modules allow for on-orbit assembly of alternate packages. As an example, a package with coaxial imagers can be configured by just adding a beam splitter module to the optical path. Individual optical filtering is also feasible if imaging in different optical frequencies is needed.



CIR Available Module Kit

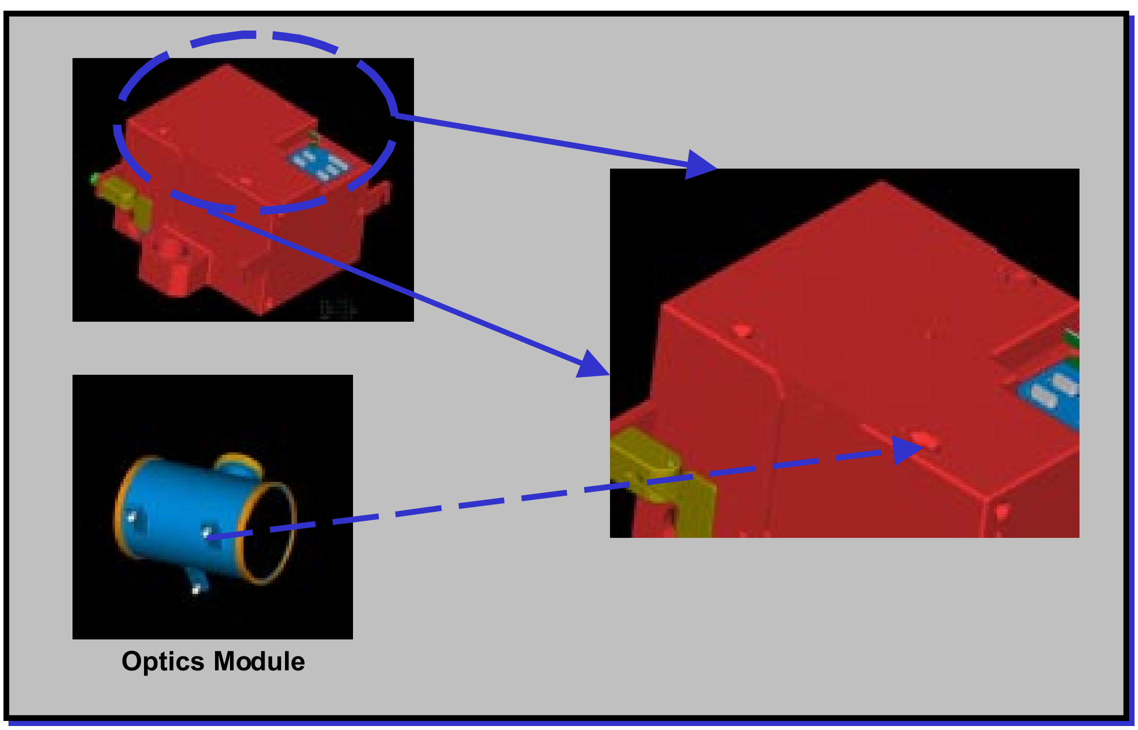
Diagnostic Control Module (DCM)

The DCM is a Common H/W module that supports all FCF racks. It contains a CPU, motor controllers, power supplies and a CAN Node. The DCM provides cooling, power, data, control and bench attachment the rest of the diagnostic modules.

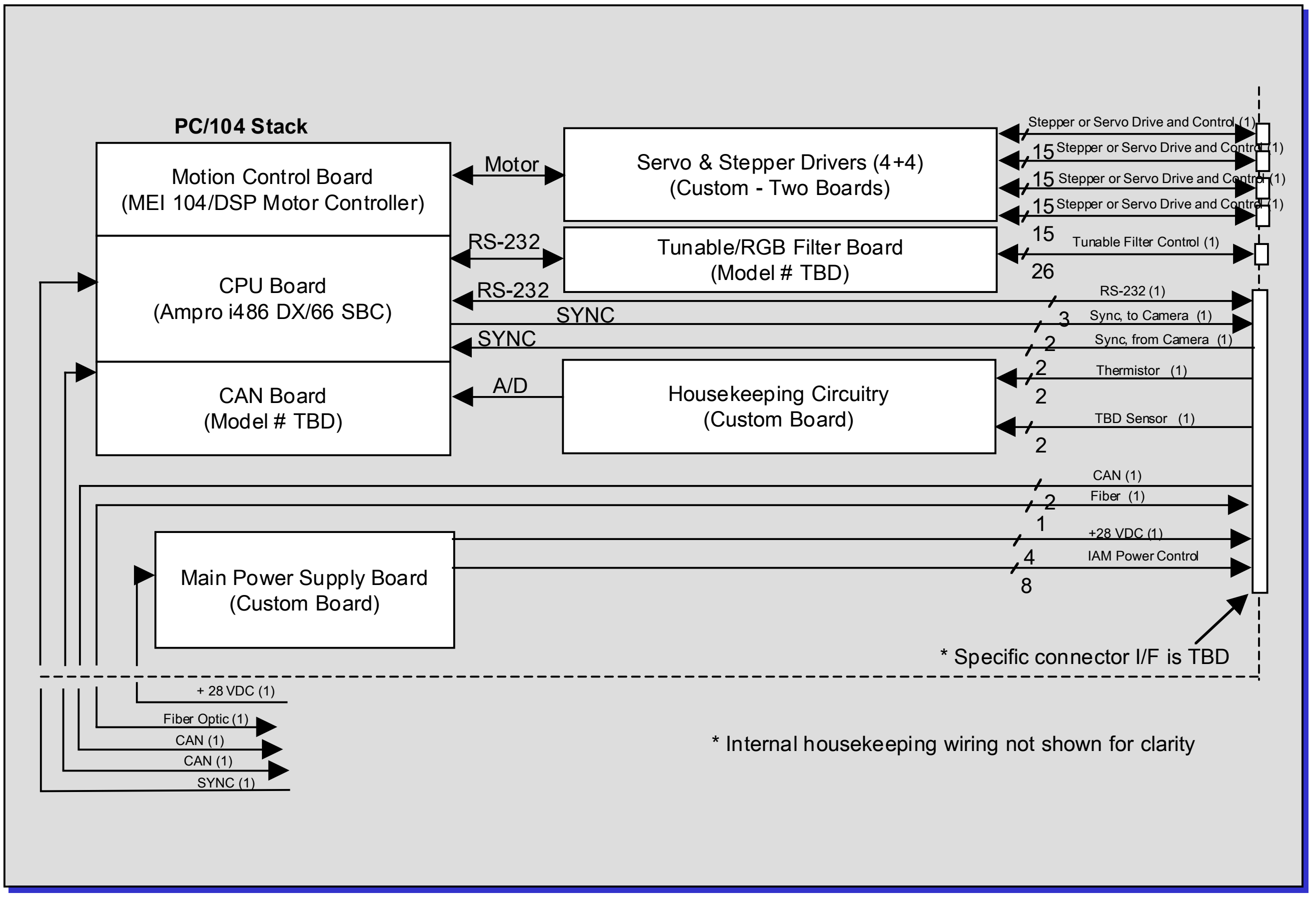


Dimensions: 133 mm (D) x 150 mm (W) x 133 mm (H)

The DCM contains a Kinematic mount to allow the attachment of the Optic Module. This is a 3-Point support that provides optical alignment. Specifications are TBD.



DCM Block Diagram

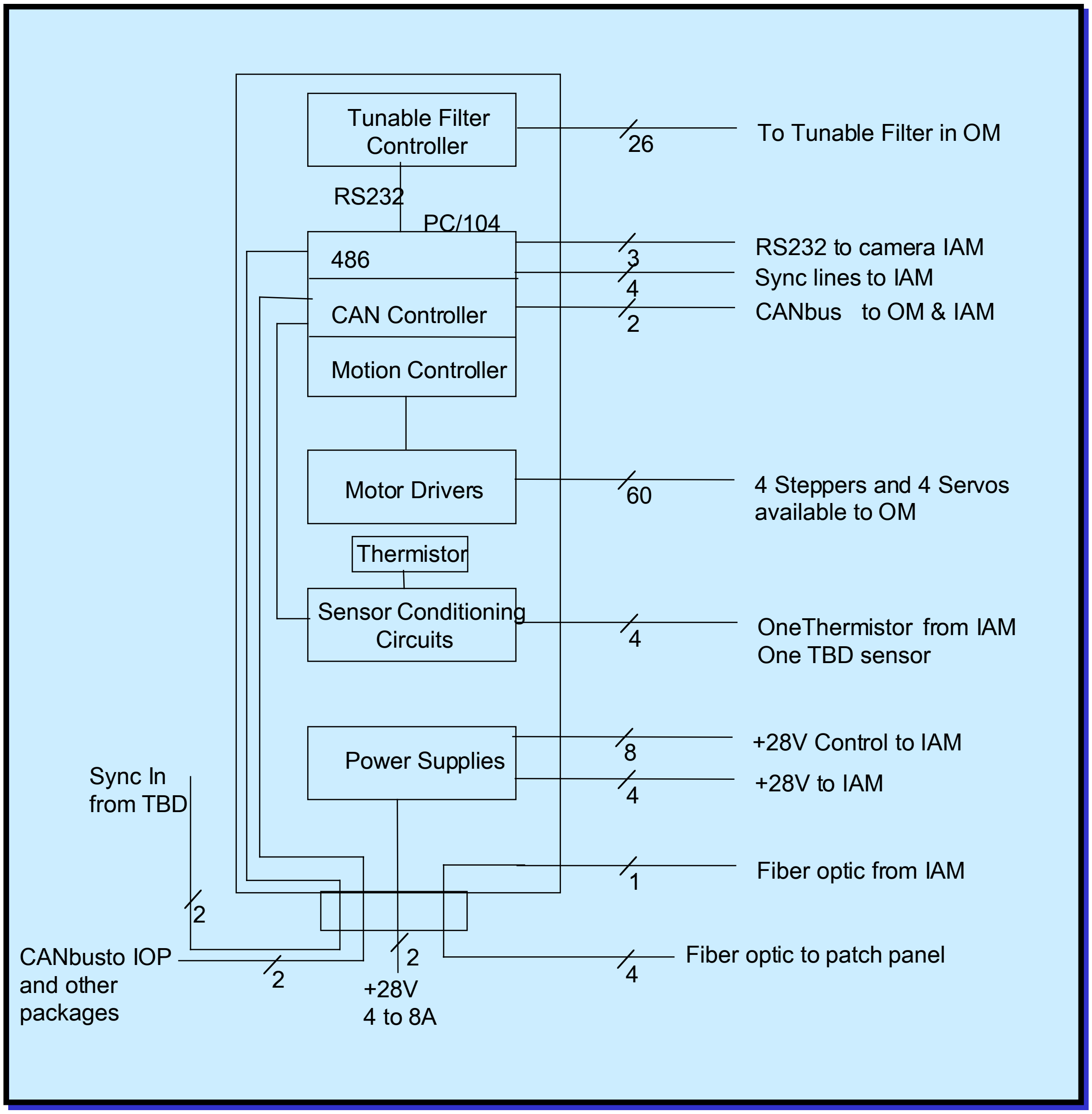


The DCM interfaces provide a set of resources to the Optics Module and the Image Acquisition Module. These interfaces include electrical, optical and data format specifications.

All Image Acquisition and Optics Modules must be designed to meet the DCM interface definitions. Specific OM and IAM modules are not required to utilize all DCM interfaces but only those needed to implement specific diagnostics features that are required by science.

The DCM also provides air passage to the IAM directly from the air cooling outlet on the Optics Bench.

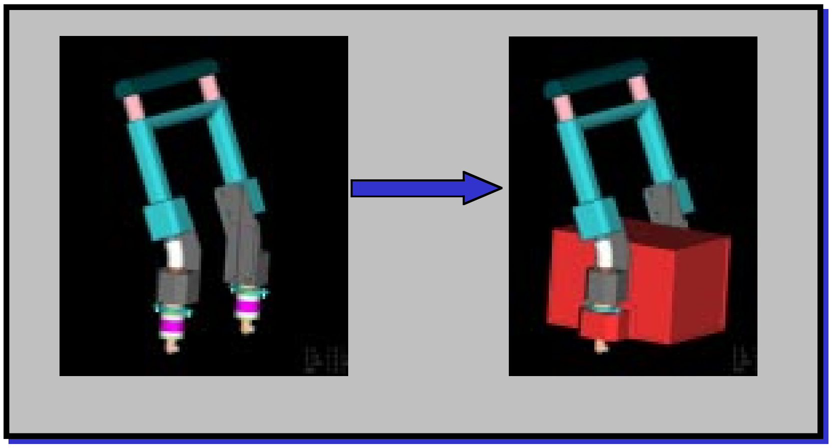
DCM Electrical and Data Interfaces



DCM Optics Bench Interface

The DCM is installed on the Optics Bench using the CIR Latch. The Latch engages on the DCM base and permits the handling and installation of the DCM (or the assembled diagnostic package) on the bench, providing both mechanical attachment and electrical connection to the UML.

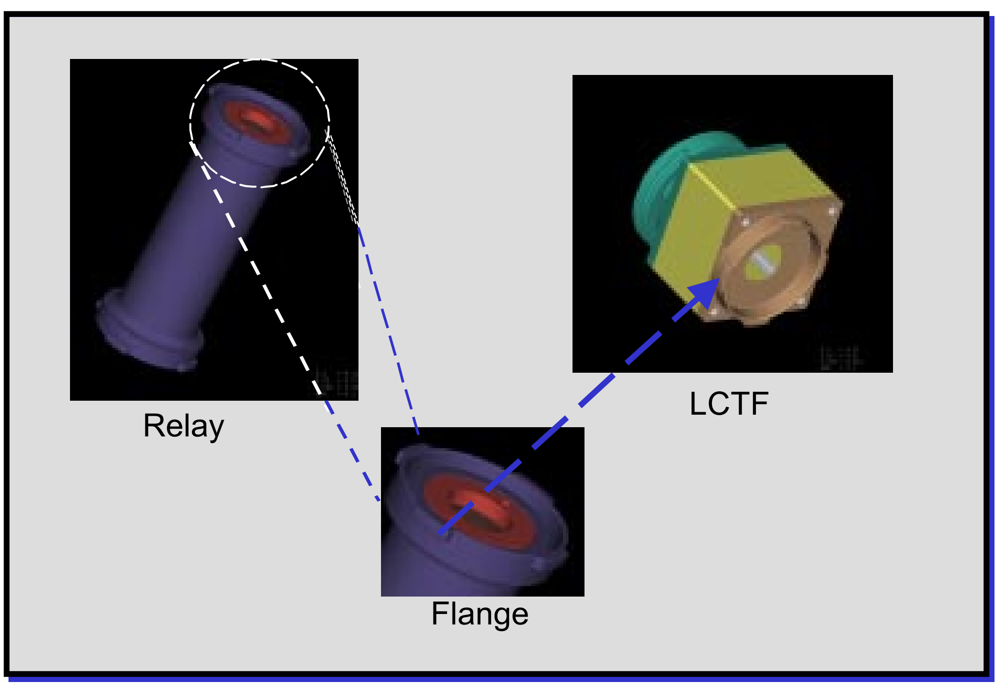
The latch is removable. The same latch is used to remove and install packages from location to location.



A quick squeeze and release of the handle allows engagement of the DCM on the Optics Bench. The latch provides mechanical bench interfacing with an alignment accuracy of 100 microns. In addition, it allows accurate electrical pin mating for the electrical connection.

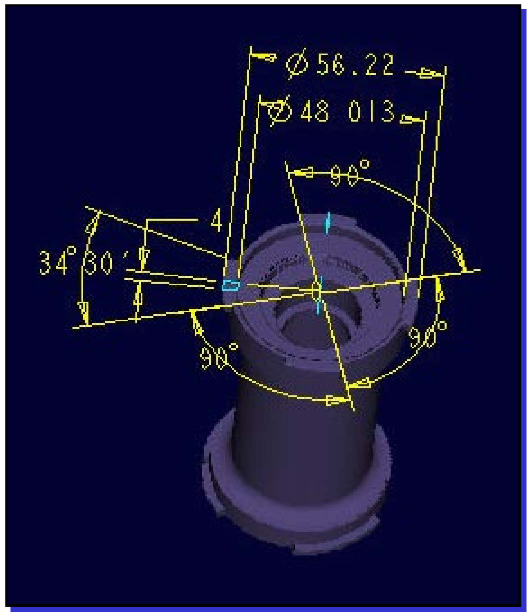
Diagnostic Modules Mechanical Interfaces

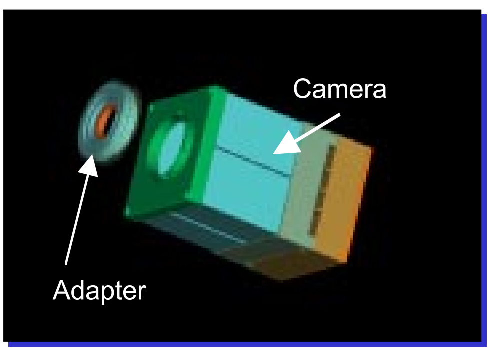
Each diagnostic module is designed to contain a flange to allow mechanical interfacing with modules with each other. A four tap design is used to align



male and female portions. A simple twist ensures engagement of components.

The design permits the addition of modules without the design of a new entire package, when science requires diagnostic components not included in the CIR provided kit.





The CIR kit also contains a flange to C-Mount adapter. This module allows the interfacing of CIR provided optical components with standard commercial video cameras.

Software and Data Interfaces

Image Processing and Storage Units (IPSU)

The CIR provides four image processing and storage units. The IPSUs are computer systems tailored to perform data acquisition from IAM (camera), data storage, image processing, and control.

There are two types of IPSUs. Two of them are packaged in a single unit, the Image Processing Package (IPP) and two are packaged in single units, they are the Common IPSUs. Common IPSUs carried their name because they can be located in all FCF racks.

The IPP IPSUs are VME and PC104 based units. They support high real-time image processing requirements and are specially tailored to support the IAM containing a SMD 1M60 digital video camera. Each IPSU in an IPP has 36 GB of storage capability. The IPP interfaces to the Optics Bench in the same manner as a DCM. Because of its size and electrical interface requirements, the IPP can only be located in UML #3, #5 and #7.

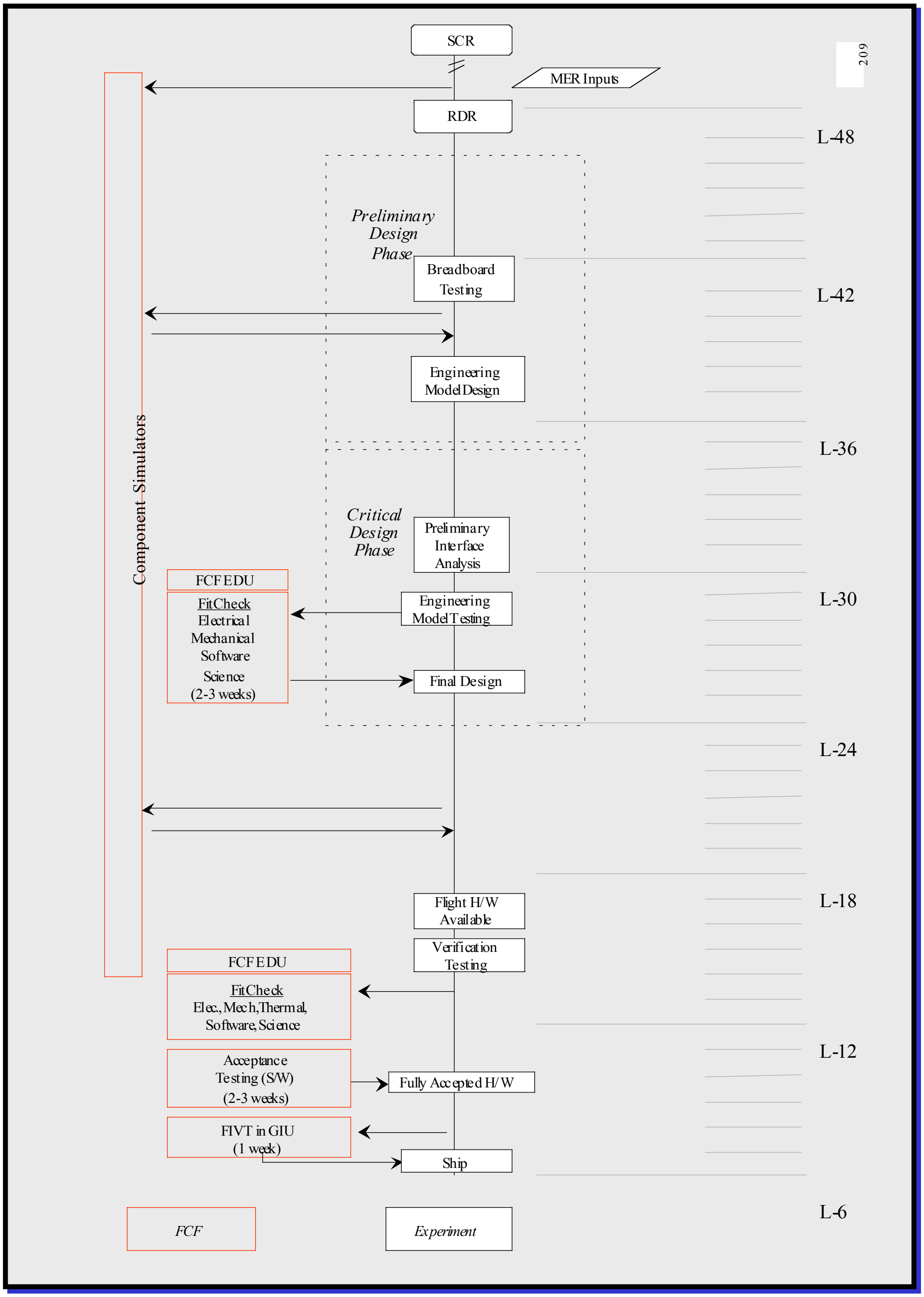
The Common IPSUs are Compact PCI and Pentium based and include a Digital Signal Processor and acquisition board. The Common IPSUs support a wide range of digital cameras format and they can be located in all CIR UMLs.

All CIR IPSUs provide an analog output for image display to the Station Support Computer if display to the crew is required.

While configured to acquire images from the CIR cameras, the IPSUs can be located in either the SAR or FIR. Data communication from rack to rack is achieved via fiber optic cable.

PI EXPERIMENT DEFINITION

The following flow chart illustrates the process for selected experiments to be accommodated in the FCF Combustion Integrated Rack aboard ISS **(*)**. This process contains several reviews and milestones starting with the Science Concept Review (SCR) and the Requirements Definition Review (RDR).



(*) This Process may not be applicable for International Partners

After selection for the flight program, an experiment will enter the experiment definition phase. The purpose of this phase is to establish the science concept. The primary review in this phase is the Science Concept Review (SCR). The purpose of the SCR is to establish that the scope and feasibility of the experiment have been adequately addressed and to propose a definitive flight experiment. A well defined and clearly written Science Requirements Document (SRD) is crucial for a successful SCR. The SRD, written for both peer scientists and engineers, describes the scientific justification, the need to conduct the experiment in microgravity, and the necessary requirements for the experiment. The SRD does not, however, contain detailed concepts or engineering drawings of the proposed experiment. General content of an SCR and a table of contents for an SRD included in the next sections of this document for reference.

Assuming that it is determined that the investigation should be carried out in hardware built specifically for that experiment, the activity then enters the hardware definition phase. The focus of this phase is to define the baseline hardware concept necessary to conduct the experiment and to establish the project baseline - including the project planning documentation. The primary review in this phase is the RDR. The purpose of the RDR is to baseline the science requirements, assess the conceptual design and engineering feasibility, and assess the project planning. The SRD is finalized after the RDR. Upon successful completion of this phase, the authority to proceed is given for flight development. At this point a significant emphasis is placed on the engineering activities associated with design, fabrication, assembly and testing of the flight instrument.

Management of the hardware development phase (Preliminary Design Phase and Critical Design Phase) is the responsibility of the Program Manager. During this phase, the hardware is designed, fabricated, assembled and tested. Included in the testing are the science verification tests to insure that the hardware can perform the functions required to meet the science requirements of the various experiments. Standard flight hardware development design reviews, such as the Preliminary Design Review (PDR), the Critical Design Review (CDR), and the Preship Review (PSR), occur during this phase. Procedures for flight experiment, mission timeline, and crew training are developed. Development concludes with the delivery of the flight hardware for mission integration.

SCIENCE CONCEPT REVIEW OUTLINE

i. Welcome (NASA GRC Division Chief or Program Manager)

ii. Instructions to Science Panel (NASA Enterprise Discipline Scientist)

0. Executive Summary (PI)
1. Goals/Objectives
2. Proposed Space Experiment (concept diagram)
3. Benefits (potential application)

1. Introduction and Background (PI)
1. Description of Science
2. Brief Historical Overview of Science
3. Currently Active Research
4. Current Status of Understanding
5. Gaps in Understanding this Experiment Plans to Fill

2. PI Research Related to Proposed Space Experiment (PI)
1. Experiments - 1g Laboratories, Drop Towers, and Aircraft
2. Models - Numerical and Analytical

3. Proposed Space Experiment (PI)
1. Objective and Hypothesis of Proposed Investigation
2. Benefit to Science and Technology
3. Flight Experiment Description
4. Science Requirements
5. Test Matrix
6. Success Criteria (minimum and complete)
7. Anticipated Results

4. Justification for Extended Duration Microgravity Environment (PI)
1. Limitations of Terrestrial (1-g laboratory) Testing
2. Limitations of Drop Towers and Aircraft
3. Need for Accommodations in the ISS, Space Shuttle or Sounding Rocket
4. Limitations of Modeling Approaches

5. Use of Data Obtained from Proposed Space Experiment (PI)
1. Data Reduction and Analysis
2. Model or Hypothesis Verification

6. Proposed Space Experiment Concept (PS or PI)
1. Description of Experiment Concept (cartoon and block diagrams)
2. Measurements and Diagnostics Required
3. Experiment Procedure

7. Science Plan to RDR (PI)
1. Identify Critical Tasks and Plans for Resolution
2. Other Science Activities

8. Summary (PI)

9. Engineering Plan to RDR (PM)
1. Identify Critical Engineering Feasibility Issues
2. Develop Plan for Resolution of Engineering Feasibility Issues
3. Develop Schedule and Costs

10. Rough Order of Magnitude Schedule and Costs to Flight (PM)

11. Science Panel Caucus (PS to attend as an observer and answer questions)

12. Science Panel Feedback to PI

13. Concluding Remarks (NASA Enterprise Discipline Scientist)

SCIENCE REQUIREMENTS DOCUMENT OUTLINE

i **SIGNATURE PAGE**
ii **NOMENCLATURE**
iii **ACRONYMS**
iv **TABLE OF CONTENTS**
v **LIST OF TABLES**
vi **LIST OF FIGURES**
0.0 **EXECUTIVE SUMMARY**
1.0 **INTRODUCTION AND BACKGROUND**
- 1.1 Brief Overview of Scientific Topic
- 1.2 Brief Literature Survey
- 1.3 Current Status of Understand
- 1.4 Knowledge Still Lacking

2.0 **PI'S RELATED RESEARCH AND PROPOSED SPACE EXPERIMENT**
- 2.1 Experiments - 1g Laboratories, Drop Towers, and Aircraft
- 2.2 Models - Numerical and Analytical
- 2.3 Objective and Hypothesis of Proposed Investigation
- 2.4 Flight Experiment Description and Concept
- 2.5 Anticipated Knowledge to be Gained, Value, and Application

3.0 **JUSTIFICATION FOR EXTENDED DURATION MICROGRAVITY ENVIRONMENT**
- 3.1 Limitations of Terrestrial (1g laboratory) Testing
- 3.2 Limitations of Drop Towers and Aircraft
- 3.3 Need for Accommodations in the ISS, Space Shuttle or Sounding Rocket
- 3.4 Limitations of Modeling Approaches

4.0 **EXPERIMENT PLAN**
- 4.1 Flight Experiment Procedure
- 4.2 Flight Experiment Plan and Test Matrix
- 4.3 Postflight Data Handling and Analysis
- 4.4 Ground Test Plan
- 4.5 Mathematical Modeling

5.0 **EXPERIMENT REQUIREMENTS**
- 5.1 Science Requirements Summary Table
- 5.2 Test Sample
- 5.3 Experiment Chamber
- 5.4 Temperature Measurement and Control
  - 5.4.1 Range, Accuracy and Response Rate
  - 5.4.2 Location and Number of Sensors
  - 5.4.3 Sampling Rate
- 5.5 Pressure Measurement and Control
- 5.6 Flow Rate
- 5.7 Imaging
  - 5.7.1 Type
  - 5.7.2 Frame Rate
  - 5.7.3 Field of View and Resolution
  - 5.7.4 Depth of Field
  - 5.7.5 Number, Orientation of Cameras
- 5.8 Environment
- 5.9 Acceleration - Magnitude, Direction, and Frequency Range
- 5.10 Astronaut Involvement and Experiment Activation
- 5.11 Telepresence
- 5.12 Postflight Data Deliverables
- 5.13 Success Criteria
  - 5.13.1 complete Success
  - 5.13.2 Minimal Success

6.0 **REFERENCES**
7.0 **APPENDIX – EXPERIMENT DATA MANAGEMENT PLAN**

PAYLOAD PROCESSING AND INTEGRATION SUPPORT

An extensive amount of ground support equipment will be made available to support processing, integration and check-out the Principal Investigator's experiment hardware and software prior to flight. In addition to the on-orbit CIR flight rack, there will be three additional supporting racks on earth. They are a Ground Integration Unit (GIU), an Experiment Development Unit (EDU), and a Payload Training Center (PTC) Trainer.

Engineering Development Unit (EDU)
The CIR EDU will be a high fidelity model, very similar to the CIR flight model. It will be located at GRC and made available to experiment developers during their hardware and software development and pre-flight testing. This unit will be used for interface verification and configuration selection testing.

Payload Training Center (PTC) Trainer.
The Payload Training Center (PTC) Trainer, which will be deployed in the PTC at Johnson Space Center (JSC), supports crew training. It will contain flight-like crew interfaces, and be comprised of mock-ups, brassboard level components and other non-flight components. The PTC Trainer will include a standard experiment equipment trainer, that can be used to train on the installation of a generic experiment chamber insert or modular experiment computer. This fully integrated PTC Trainer will be supplemented with experiment specific part task trainers, as necessary, that may be required to train the crew on the operation and maintenance of the experiment hardware.

Ground Integration Unit (GIU)
The CIR GIU will be located at GRC and will be used for final interface verification testing of experiment hardware, as well as for on-orbit troubleshooting. The GIU will be virtually identical to the CIR flight unit.

<u>Experiment Integration and Operation</u>
Because the FCF and CIR hardware are designed to reduce the overall cost of individual experiments by providing substantial common capabilities, the experiment equipment alone cannot perform the scientific objectives of the experiment. Therefore, a multi-tiered integration support scheme, consisting of CIR simulator, experiment engineering, and experiment flight hardware integration testing, is envisioned.

FCF Simulator Testing
Simulators of FCF/CIR flight hardware will be available to experiment developers during the development of their hardware. Simulator equipment will be designed

to emulate those interfaces between the facility and the experiment that must be tested early and often throughout the experiment development, so as to assist in the design of the experiment hardware and software. Simulators for the CIR will be produced to simulate, at a minimum, electrical and C&DH interfaces, and be used extensively for interface verification testing between the facility and the experiment.

Simulators of available FCF/CIR configurable equipment, such as cameras, light sources, filter cartridges, etc will also be provided for PI use. Early in the experiment development cycle, the FCF/CIR configurable equipment will require evaluation for suitability for use on a particular experiment. In addition to this engineering evaluation, diagnostic simulators may be required to support science testing prior to the experiment Requirements Definition Review.

Once a particular piece of FCF/CIR configurable equipment has been selected for use by an investigator, the experiment developer must conduct testing to optimize the configuration of the equipment. This testing will be used to select the settings, parameters, test sequence, and overall configuration of the FCF/CIR configurable equipment.

Experiment Engineering Hardware Testing
The next level of integration support conceptualized is testing between experiment engineering hardware and the CIR EDU. This testing will satisfy the following objectives:

- Interface verification (mechanical, electrical, thermal, software and fluid)
- Preliminary science acquisition
- Preliminary FCF configuration and parameter selection
- Test sequence identification
- Crew procedure validation

This testing will nominally occur 24 months prior to launch, and is expected to last 2-3 weeks for each experiment.

Experiment Flight Hardware Testing
Eventually, the experiment flight equipment will be integrated into the EDU to satisfy the following objectives:

- Interface verification (mechanical, electrical, thermal, software and fluid)
- Ground science acquisition
- Final CIR configuration and parameter selection
- Final test sequence identification
- PI familiarization training
- Experiment acceptance testing

A flight-like user interface will be provided at this stage of the integration testing. This testing will nominally occur 15 to 9 months prior to launch, and is expected to last 2-3 weeks for each experiment.

GIU Testing

The last level of integration support, which provides the highest fidelity integration testing platform, is referred to as the Final Interface Verification Testing (FIVT). Completely tested and accepted experiment equipment will be integrated into the GIU. This test will consist of high-fidelity interface verification, and will include an abbreviated mission simulation in order to fully exercise the software interface. This test will last approximately 1-3 days and occur approximately 1 to 2 months prior to shipping the hardware to KSC. The hardware and software configuration will be frozen at the successful conclusion of this test. If any changes in hardware or software are required after the FIVT, the FIVT will normally be repeated.

Operations

As mentioned above, command and control of microgravity combustion experiments conducted on-board ISS in the FCF/CIR will be orchestrated from the TSC located at the Glenn Research Center. The TSC is responsible for distributing the necessary voice, video and/or data to the remote PI site.

Post-Landing Payload Activities

Some PI's may require additional ground data to supplement the actual microgravity data obtained aboard the ISS. If necessary, the EDU will support additional science acquisition, on a non-interference basis. This testing, when necessary, is expected to last approximately 1-2 weeks.